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SEA DUCT: A DEEP-SEA COMPUTER-CONTROLLED RECIRCULATING
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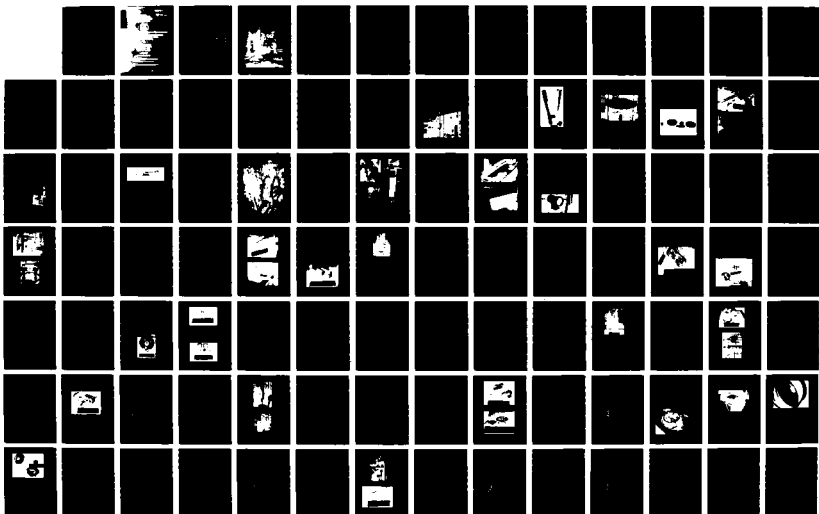
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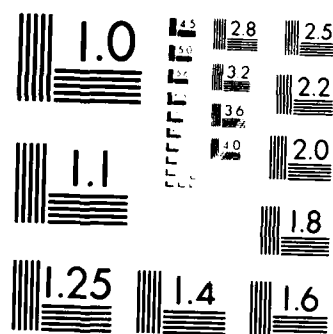
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FINAL REPORT

SEA DUCT: A DEEP-SEA COMPUTER-CONTROLLED
RECIRCULATING FLUME FOR THE STUDY
OF SEA FLOOR STABILITY

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TECHNICAL REPORT

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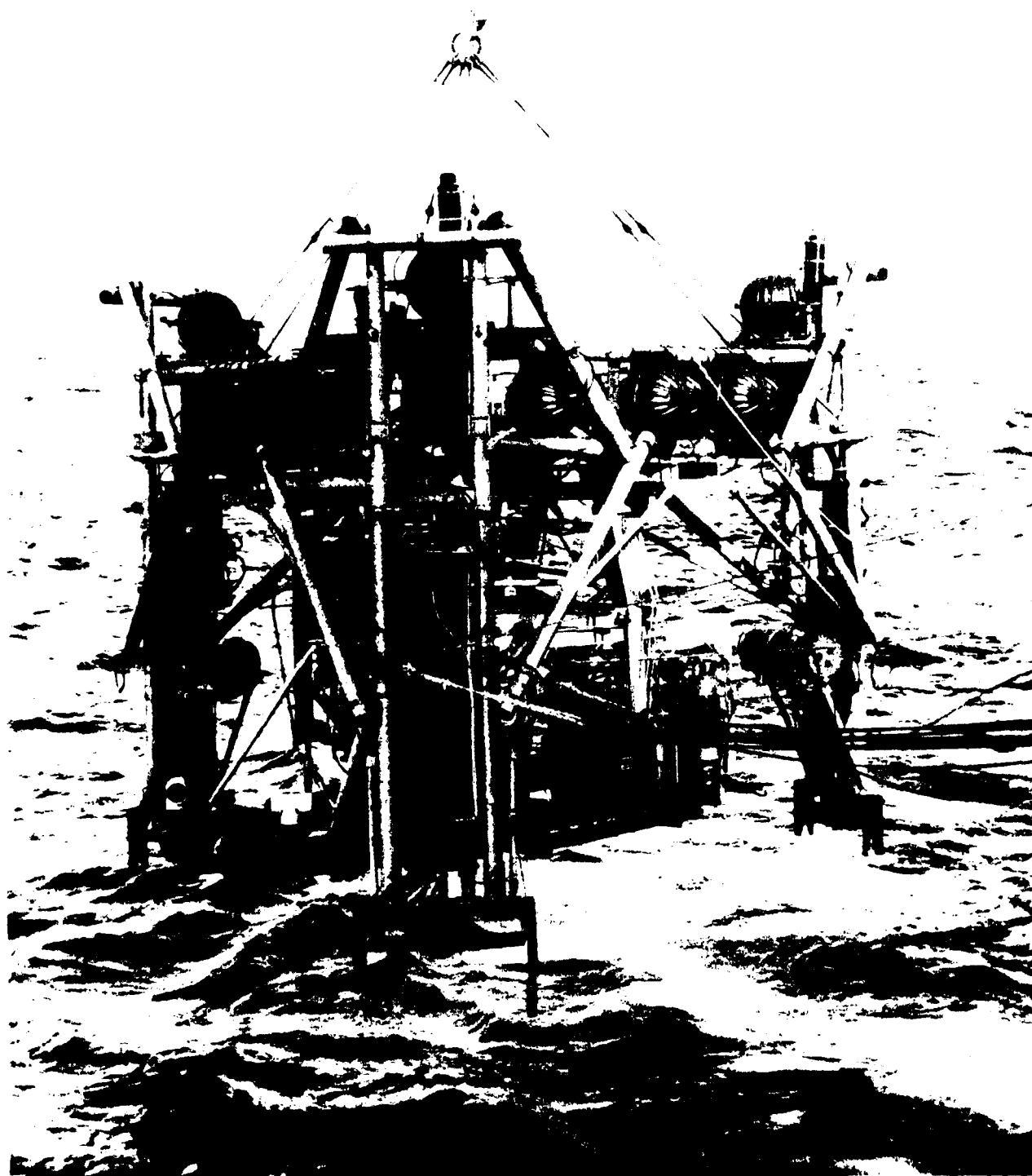
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Dr. Albert J. Williams, Acting Chairman
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1986 At-Sea Deployment of the Sea Duct Structure From the R/V KNORR.

This report consists of three sections. The first subdivision discusses the electro-mechanical systems and deployment-recovery techniques, while the second portion covers the microprocessor controller and its support equipment. The third section contains the appendices, which consists of program listings, schematics, system and deployment check-list, etc. Because of the large size and specific nature of the third section, it has been printed in a separate volume. Copies of the appendices are obtained by contacting William Terry at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Page numbers in the first section are prefaced with an "A" (i.e. A-1, A-2, etc.). Page numbers in the second section are prefaced with a "B". Figure references in the mechanical section (Section A) are numbered 1a, 2a, etc. Figures in the second section are numbered 1b, 2b, etc. Pages in the appendix volume are prefaced with the letter corresponding to the appendix letter.

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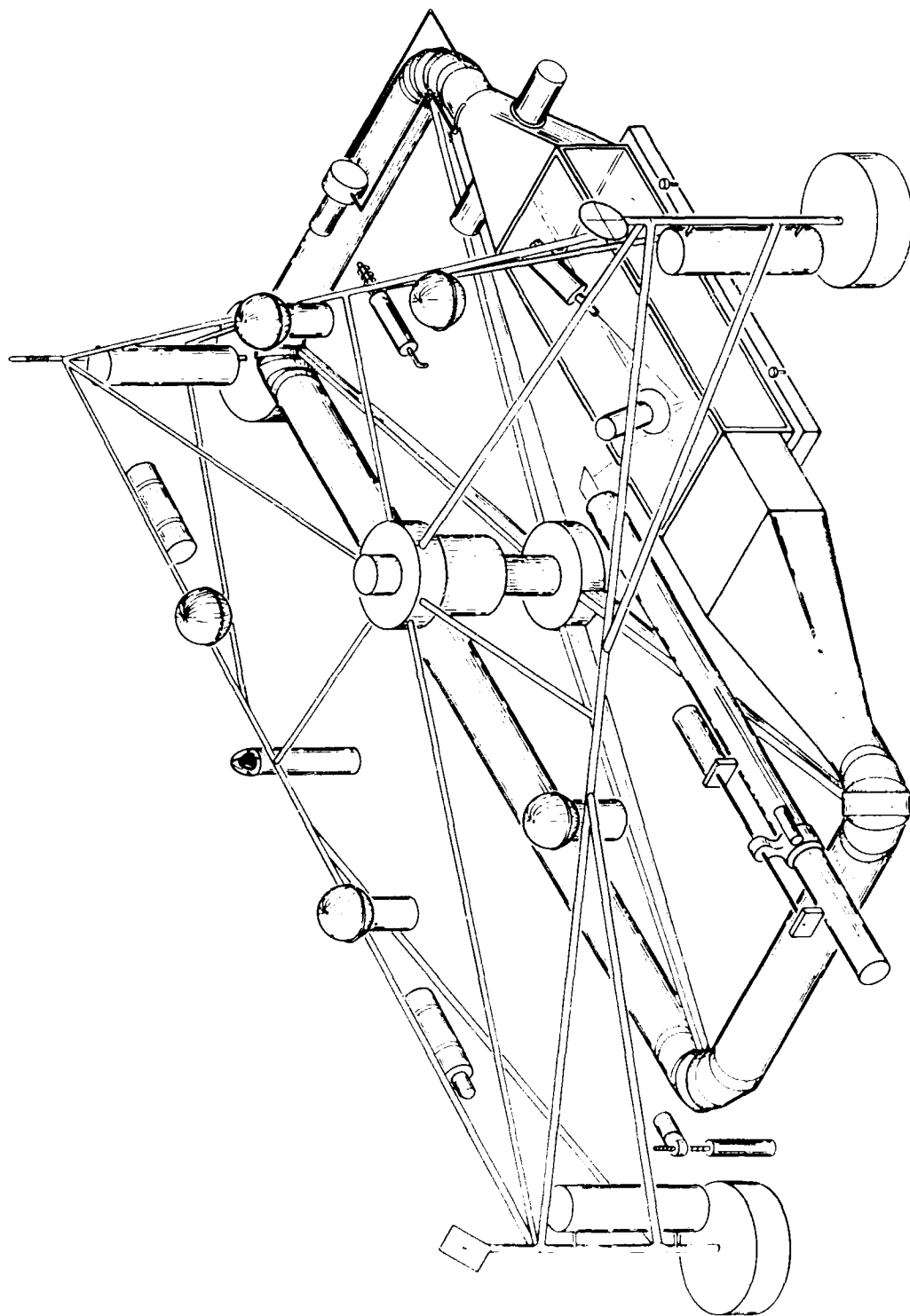
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ARTIST CONCEPT OF
HEBBLE BENTHIC WATER TUNNEL

FIG. 14

ABSTRACT

The Sea Duct Ocean-Bottom Laboratory is a computer controlled recirculating inverted flume for the in-situ study of sediment transport. It is designed to measure the sea floor response to controlled currents analogous to those generated by surface waves, tidal, or deep ocean storms.

The external support frame is an equilateral triangle with sixteen foot sides. It is 12 feet high, has an air weight of 12,500 lbs., and a 2800 lb. submerged weight. Three lead acid battery packs located at the vertex of the triangle legs provide power for the recirculating water pumps, hydraulic power, and ancillary equipment.

The inner rotatable structure consists of a 4 foot long by 2 foot wide open bottom windowed test section that is 9 inches high. It is connected to 30 feet of 8 inch tube configured as an elongated toroid. Above the test section is a traverse carriage with stereo camera, flash, and a laser Doppler velocimeter to measure fluid stresses.

Internal flow velocities are controlled and can be ramped up to approximately 2 ft/sec providing shear stress sufficient to scour sand, silts, and fine clays. Water and sediment sampling devices obtain specimens from inside and outside the test section.

Acknowledgments

The development of the deep ocean recirculating flume, Sea Duct, was made possible by the Office of Naval Research, Environmental Sciences Directorate, under Contract N00014-85-C-000/NR 083-004.

Recognition and appreciation are given to the various sections within the Woods Hole Oceanographic Institution, especially those who provided expertise and considerable patience in the areas of welding, machine shop fabrication, electrical and mechanical assembly, and final shore side testing of this device.

Al Bradley made a significant contribution with his software for the pump controller. His helpful discussions, design ideas and encouragement are greatly appreciated. Al Duester was responsible for the design and testing of several of the electronic subsystems. Karlen Wannop's skill in electronic assembly, wire wrapping and record keeping is greatly appreciated, as is Martin Woodward's and Charles Peters' quality machining and design suggestions that were provided throughout the program.

Specific thanks is extended to the Graphic Arts Department for their numerous line drawings, system schematics, photographs and artist concepts used throughout this Report.

Special appreciation is also extended to Judith White for her patience and expertise in assembling and typing the data contained in this publication, and to the Purchasing Department for their untiring efforts in obtaining a wide variety of components on short notice.

To the crew of the R/V KNORR and the diver observers that made it possible to successfully deploy, test and recover the Sea Duct both in shallow dock side tests, and at 5000 meter depths, my personal gratitude is extended for a job well done.

Appreciation is also given to Marguerite McElroy, James Lynch and Wayne Vincent for shipboard photographs, and Sean Kerry for providing the computer program used in calculating deployment cable characteristics.

1.0 Discussions of the Problem and General Approach

This research effort was initiated to design, construct and demonstrate an inverted recirculating flume that would obtain measurements of the entrainment and transport characteristics of marine sediments. The device would allow the in-situ testing of models of marine sediment transport and measure the entrainment rate, particle concentration profile, settling velocities of recently entrained materials, boundary layer velocity, and stress fields.

This Report will cover in detail the preliminary design concepts, construction, weight, deployment, operational and recovery characteristics, and will include a discussion on design improvements based on experience obtained during shallow water and deep sea deployment.

The Sea Duct inverted flume was designed for use at any depth, from the surface to 5000 meters. In its present configuration, it is tethered to, and deployed by, a shipboard winch and trawl cable. An on-board, pre-programmed microprocessor sequencer directs the Sea Duct operation. A rudimentary communication link between the device and the surface is accomplished through an acoustic transmitter. It provides the surface controller with basic information concerning the initiation of a sequence and the completion of the operational function. In the case of a signal indicating an incomplete operation, it allows the surface controller to direct the microprocessor to repeat its command. Step functions controlled by the microprocessor as well as accumulated test data is stored on tape for processing on surface return. The acoustic link has provisions to actuate the emergency recovery release mechanisms and will override the sequence controller for these last resort recovery operations.

EXPLODED VIEW OF HEBBLE BENTHIC WATER TUNNEL

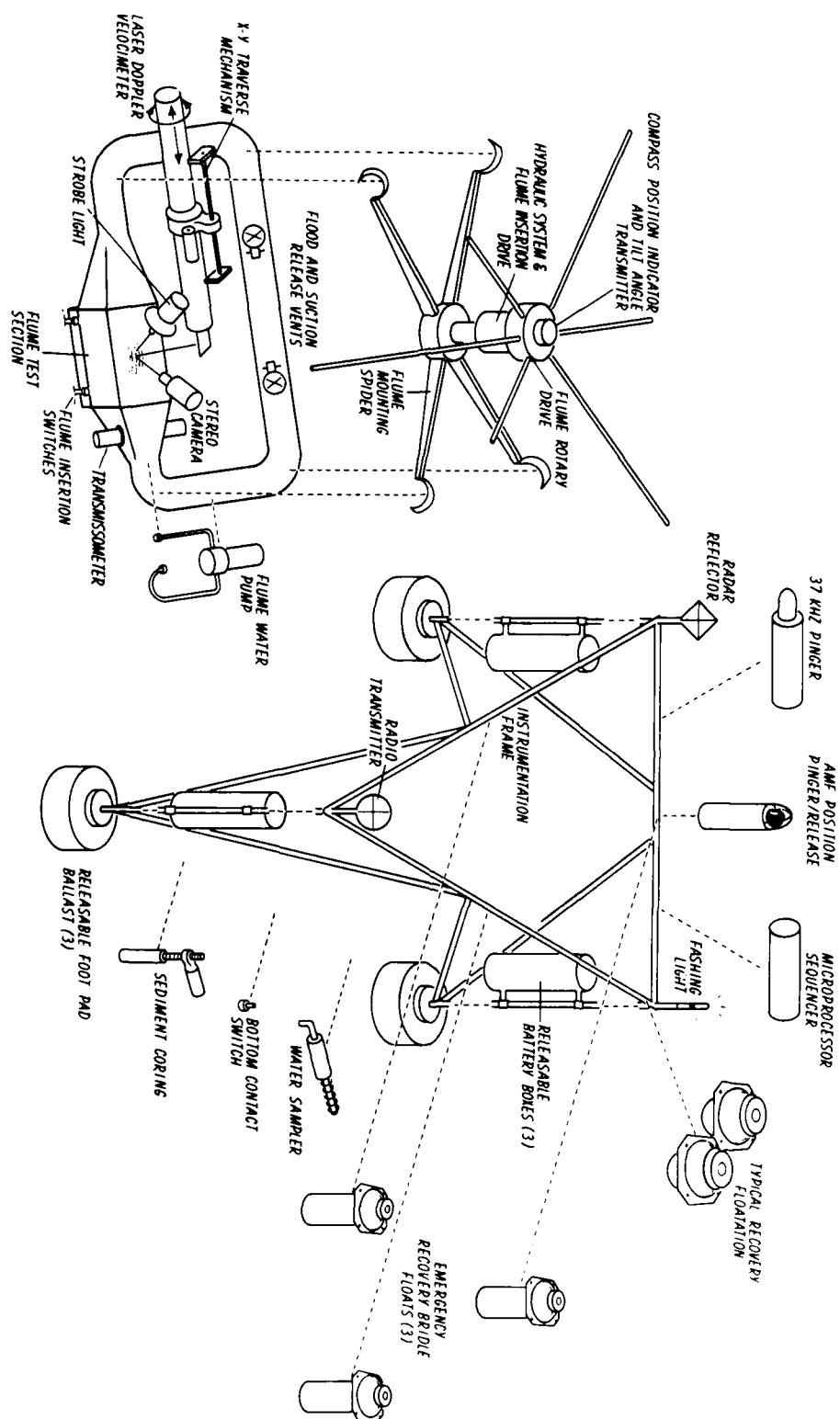


Fig. 2a

Photographic equipment, sediment and water sampling, a transmissometer and laser Doppler velocimeter complete the sampling and scientific data gathering apparatus.

2.0 Primary Design Objectives

The following design objectives are considered as the main engineering and system goals for the construction of the autonomous recirculating sea floor flume. Referring to the artist concept, Figure 1, the device consists of an exoskeleton as the fixed main support, an inner carousel which allows the duct and rectangular test section to be rotated a full 360 degrees, providing a means of obtaining a pre-selected alignment with bottom sediment ridges and furrows.

On completion of flume positioning, the open bottom 'cookie cutter' test section is slowly inserted into the sediment until a complete seal is obtained around the knife edge base. The flume duct and test section are now a sealed assembly. A specially designed pump recirculates water in the duct. A micro-processor sequencer directs the device through a series of step velocities to simulate the characteristics of a deep ocean storm or tidal flow.

The deep ocean Sea Duct design requires the device to be an autonomous assembly. Figure 2 provides an exploded view of the necessary support components. As illustrated, the exoskeleton will have three releasable foot pad ballast weights and a set of three lead acid battery packs, each secured on a vertical leg at the vertex of the equilateral triangular frame. They are designed with a release mechanism to allow them to be jettisoned in an emergency.

A passive radar reflector, flashing light, and radio transmitter are considered as back-up surface recover devices when the Sea Duct makes an untethered descent and ascent in the open ocean. Three emergency recovery floats are secured to the top of the frame. Each float is attached to 1000 feet of line coiled in individual canisters. On release they float above the Sea Duct, providing a method for emergency bottom recovery through the use of a surface towed grapnel.

Deep ocean flotation is provided by glass spheres encased in protective plastic hard hats which are secured at the uppermost section of the frame to assure subsurface stability.

The rotary carousel provides the mounting structure for the recirculating duct work, flume test section, hydraulic power package and the rotary drive mechanism. A rotary position transmitter secured to the carousel provides the microprocessor with feedback in the form of angular degrees of rotation, with magnetic north used as the reference bench mark. A bottom contact switch indicates the device has landed, while a tilt angle transmitter provides a read-out of its off vertical position. A flume insertion device forces the test section cookie cutter through the sediment surface. At a pre-determined depth, limit switches halt the insertion.

A transverse mechanism secured to the test section, provides X-Y-Z motion for the laser Doppler velocimeter. A top glass plate allows internal viewing of the ocean bottom encased within the test section. A stereo camera and strobe light obtain a down-looking photographic mosaic along the tunnel's longitudinal axis.

The side ports, or optical flats, allow access for the laser beam to measure fluid velocity and stress fields at various locations in the water column. A transmissometer at the discharge end of the test section provides measurements relating to the buildup of sediment in suspension, as the fluid flow erodes the sea bed within the device.

3.0 Design and Construction Details

3.1 Fabrication of the Exoskeleton

The external frame was assembled with both 2 1/2 inch and 4 inch O.D. 6061-T6 aluminum tubing. It is a thin wall (.062") material that is filled with syntactic foam. Figure 3 illustrates the typical truss construction, with liberal use of triangular stress members.

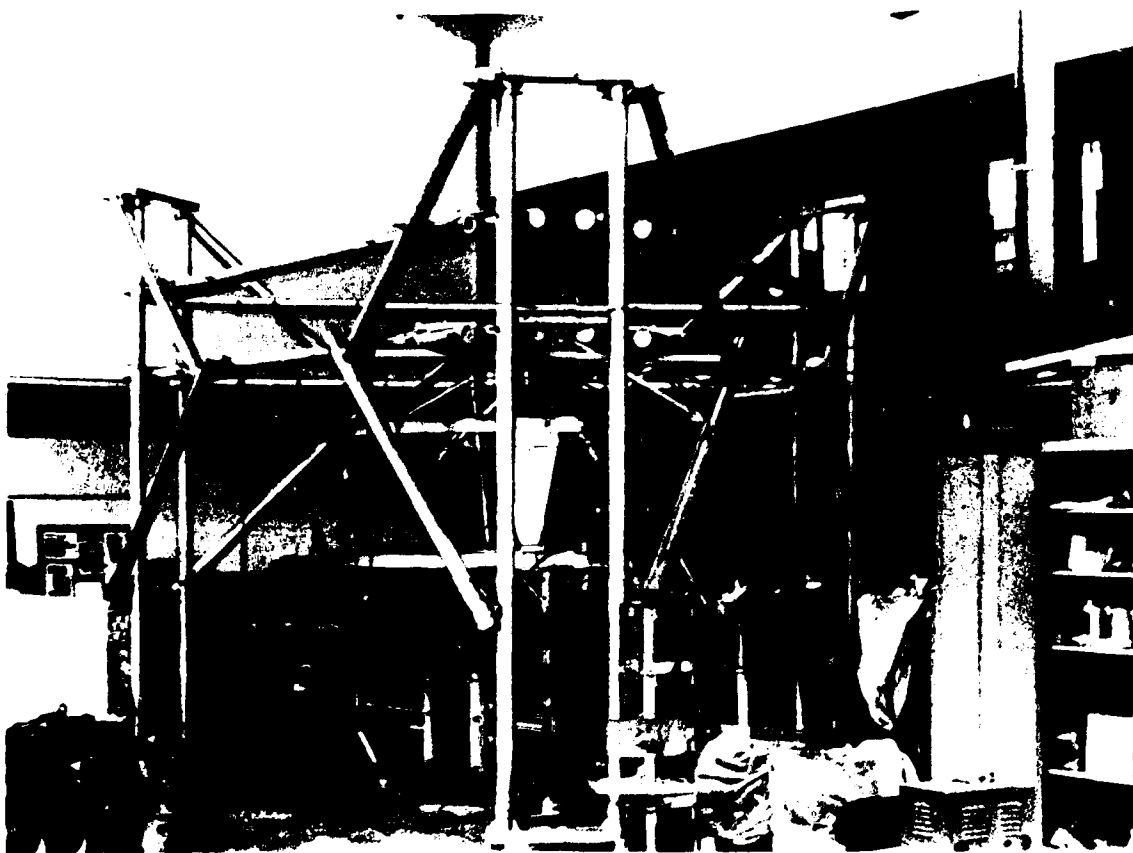


Fig. 3a. Exoskeleton Structure of Syntactic Foam-Filled Tubes

Unfortunately, the area below the 4 inch tubular angle brace must remain unobstructed to assure the Sea Duct tunnel and tube runs can rotate a full 360 degrees. During the lift mode of the loaded Sea Duct, some inward spring of the three battery carrying legs is experienced. The addition of a horizontal compression member along the base of the structure would be beneficial, and some future design effort will probably be pursued.

Calculations on both the 2 1/2 and 4 inch O.D. foam-filled tubes having a concentrated bending load applied at the center point of a 72 inch span, predict failure will occur at 1100 lbs. for the 2 1/2 inch, and 3700 lbs for the 4 inch tube. Calculations on the compressive strength of 2 1/2 inch and 4 inch foamed tubes show that a 72 inch length of 2 1/2 inch tube will fail in the buckle mode when end loaded to 8000 lbs. A similar length of 4 inch diameter tube will fail at 35,000 lbs.

The use of thin wall aluminum/foam composite sections provide the designer with a method of assembling deep water structures that are light weight with high load bearing capability. Its displacement substantially reduces the requirement for additional buoyancy in the form of individual glass spheres and blocks of syntactic foam. The 4 inch foam-filled tube provides one pound of positive buoyancy per one linear foot of length.

3.2 Structural Assembly Fittings

The fastening and joining of the 2 1/2 and 4 inch tubes required a means of spreading point contact loads over a larger surface, and of reducing twisting loads to a minimum. The design must also be capable of allowing maximum angular freedom for the installation of cross brace and truss members, and the attachments of support pay loads.



Fig. 4a. Tubular Structure Model and Swivel Vee-Block Saddles

The saddle design illustrated in Figure 4 depicts a typical tubular frame assembly secured by a through bolt and two vee-block fittings. The cross-sectioned saddles at the base of the model shows the aluminum girth ring and the center pivot that allows the saddles to rotate to any angular position required during frame fabrication.

The saddles are inexpensive to produce and were fabricated in-house. Figure 5 illustrates a typical aluminum master pattern on the left, the bottom half of the mold, a complete vee-block saddle, and the matching top half of the mold.

The mold material is a milky white liquid that is mixed with a catalyst just prior to pouring. After hand mixing, the batch is put in a vacuum jar and de-gassed at 25-30 inches Hg. until major foaming has ceased. The aluminum pattern is prepared by coating with Butcher's wax or sprayed with a

parting agent similar to silicone spray. On drying it is put in the mold form, in this case the lower portion of a plastic bottle. The mixed silicone liquid is poured around the plug mold, being careful not to trap bubbles at the pattern face.

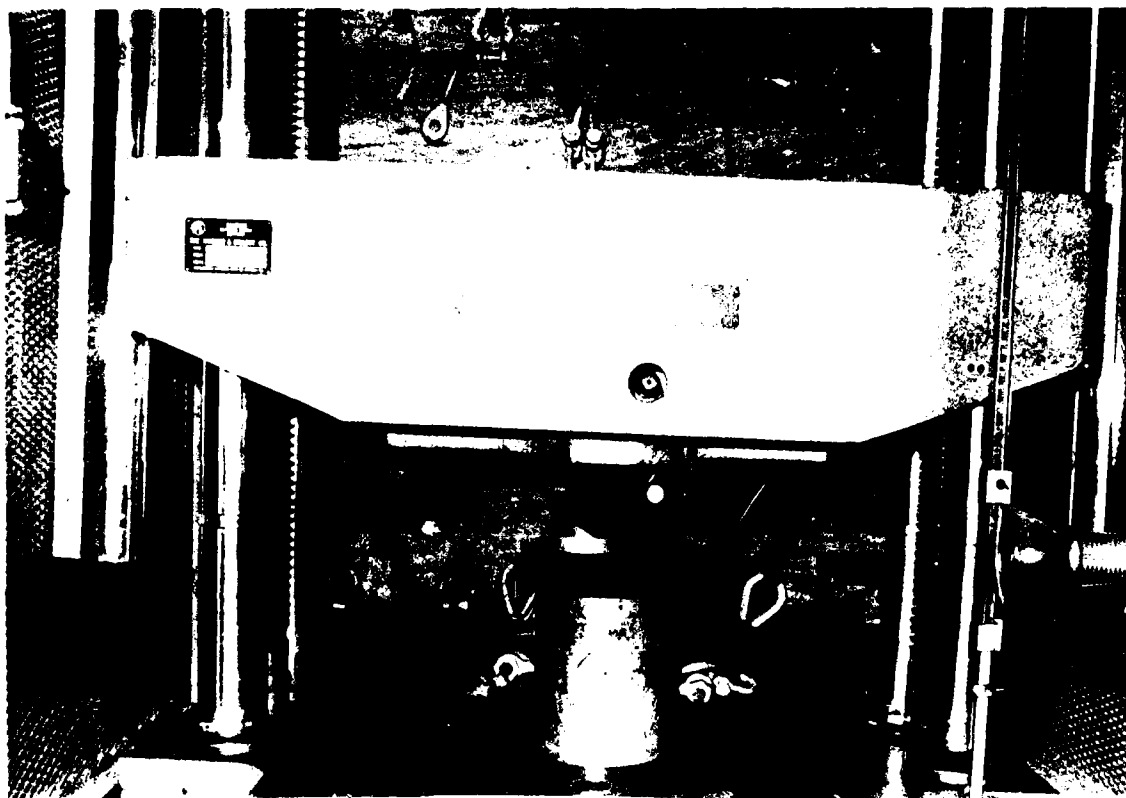


Fig. 5a. Vee-Block Saddle Pattern and Mold

The mold cures overnight at room temperature and is sufficiently flexible to peel off the pattern. The material trade name is ECCOSIL 4122 and is supplied by the Emerson Cuming Company.

The epoxy based saddle material is chockfast orange PR610TCF supplied by Philadelphia Resins Corp. It is a two part catalyst material. Again, after mixing, it is de-gassed until major foaming has ceased. Other than positioning the previously sand blasted and de-greased girth ring at the base of the

cavity, no special mold preparation is required. The chockfast will cure overnight at room temperature. The mold flexibility allows easy removal of the cast saddle. The girth ring will bond to the epoxy and becomes an integral part of the saddle. The mold is quite tough and can be used dozens of times before it must be replaced.

Test specimens of the cast vee-blocks have been immersed in sea water for a 30 day period without signs of physical or mechanical degradation. Compressive load tests using a Baldwin Universal Testing Machine (Figure 6) demonstrated the vee-blocks are capable of accepting high compressive loads before failure.

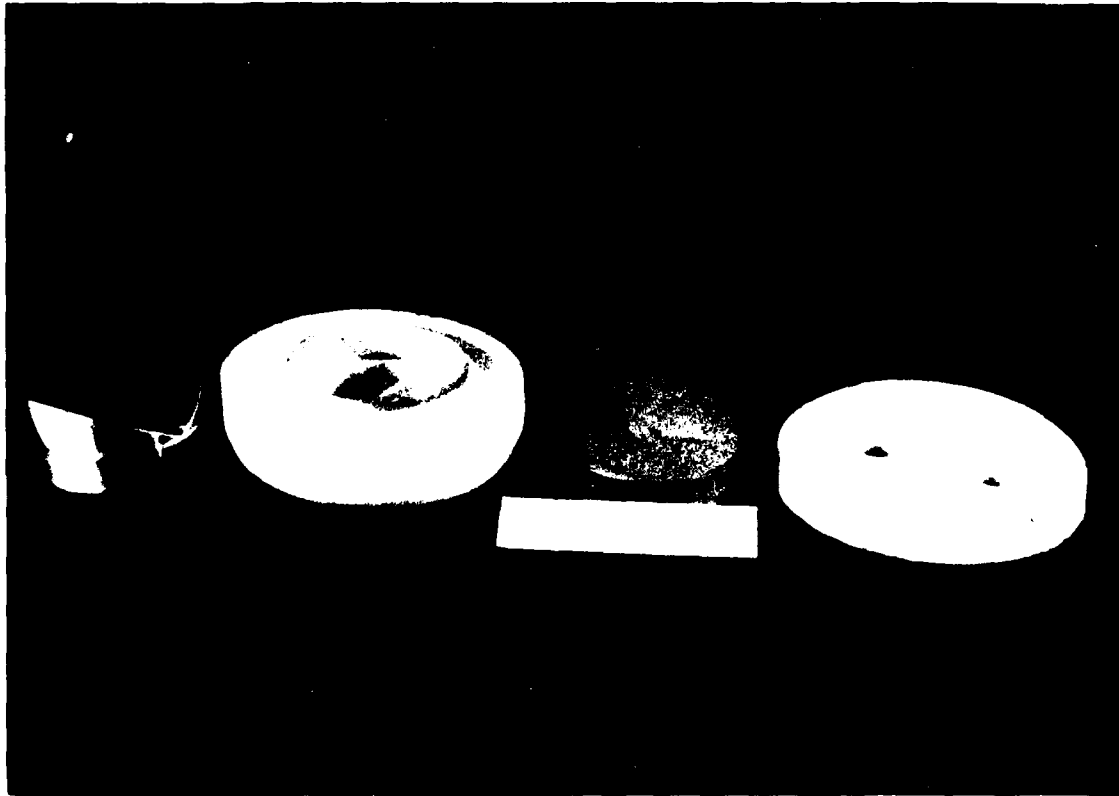


Fig. 6a. Compression Test of Cast Epoxy Tube Saddle

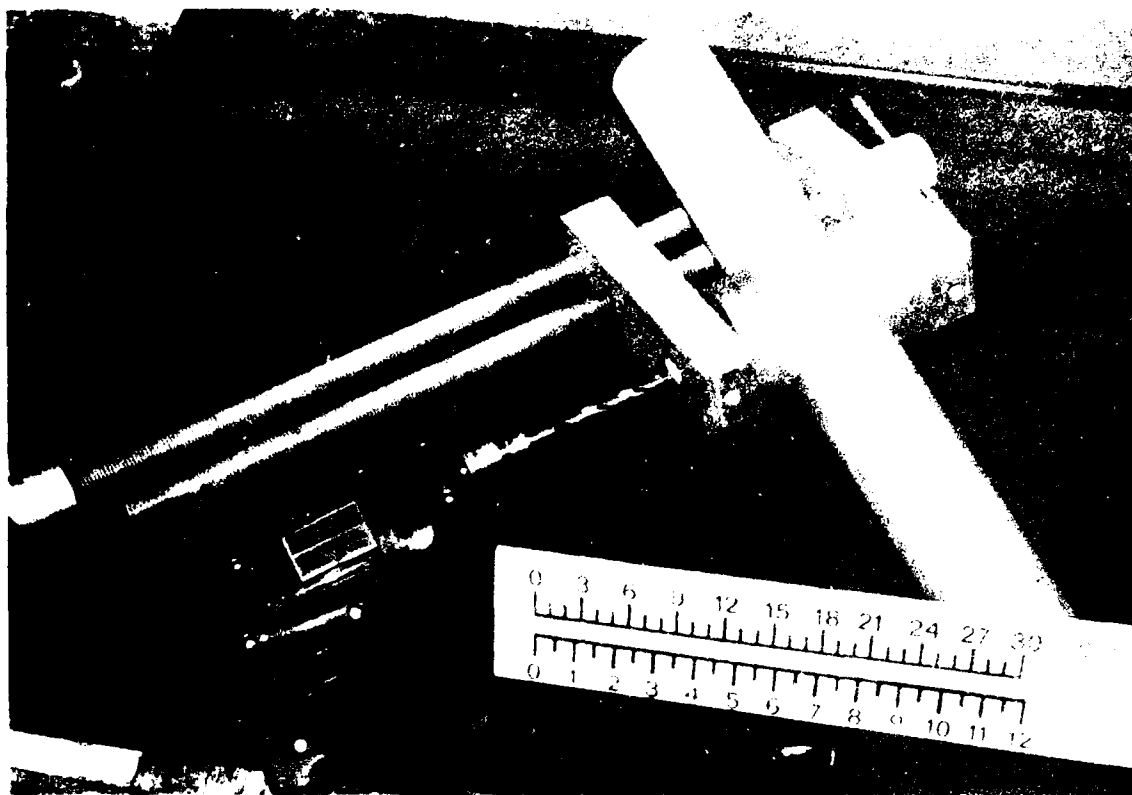


Fig. 7a. Foamed Tube Drilling Vee-Block Fixture

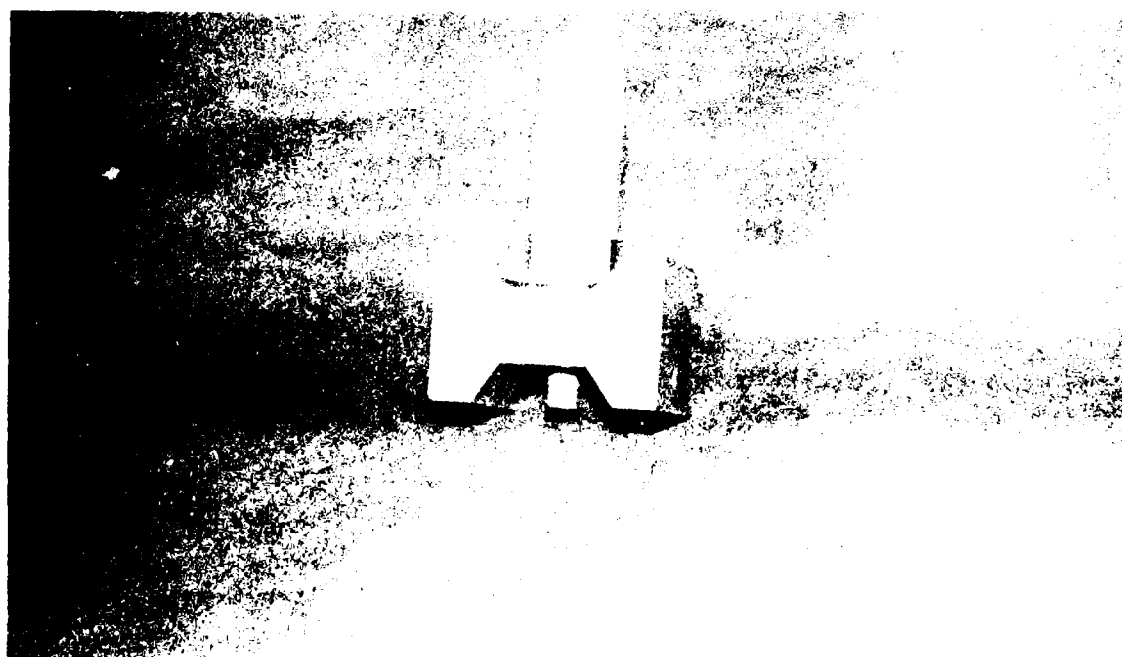


Fig. 7b. Foamed Tube Drilling Vee-Block

Tests with an aluminum girth ring molded to the base of the saddle block have demonstrated the blocks can be loaded with as high as 10,000 lbs. compressive force before yield occurs. Without the girth ring, failure (fracture at the apex of the vee-block angle) occurs at loads of 8,500 lbs.

The tubular structure of the Sea Duct is secured with 3/8 inch stainless steel threaded rods. To assure all drilled holes were in the exact center of the tube, the universal drill fixture illustrated in Figure 7 was constructed. In essence, it's an oversize vee block and adjustable clamp assembly, with a hardened steel bushing to guide the drill bit. A standard electric hand drill and 3/8 inch extension twist drill are used to penetrate both the outer aluminum shell and inner syntactic foam.

No special materials or twist drills were used to drill through the syntactic foam. However, an occasional resharpening of the drill cutting edge was required.

To reduce corrosion between the stainless steel bolts, nuts and washers, and the outer aluminum shell of the tubes, all attachment contact points were isolated through the use of plastic washers. To assure satisfactory washer contact at the circumference of the tubes, a coining die was constructed as depicted in Figure 8. It pre-forms the stainless washers as shown. When assembled with a plastic washer between it and the aluminum tube, it forces the pliable material into circular contact rather than a tangential point contact.

In view of the material mix on the overall Sea Duct structure, zinc anodes have been liberally placed throughout the assembly. A total surface area of two square feet of sacrificial zinc, in the form of 1 1/2 inch dia-

meter X 1 inch high cylindrical buttons have been bolted to the aluminum tube, channel sections, I beam structure, X-Y-Z traverse carriage, and all pressure resistant housings.

3.3 Syntactic Foam Filled Tube Mixing and Injection System

When the decision was made to fill the aluminum tubular structural members with deep water syntactic foam, several manufacturers were contacted for pricing and delivery. Being a specialized field, the amount of qualified vendors is severely limited. After considerable discussion, vendor representatives decided the quantity did not justify the special jigs and fixtures required to perform the operation.

In view of scheduling targets, it was decided to construct an in-house filling system. Syntactic foam kits were available in the form of one cubic foot packs. The kit included glass microsphere balloons premixed in an epoxy base, and the necessary catalyst. The user provides the means of mixing, degassing, and injection.

Figure 9 illustrates the mixing apparatus, a device providing the operator with the capability of mixing the glass microsphere balloons and resin under a reduced

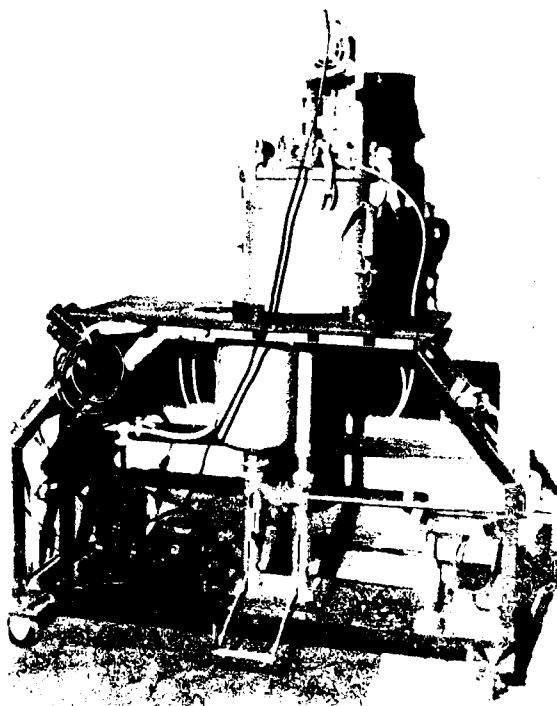


Fig. 9a. Syntatic Foam Injection Pumping Apparatus.

atmospheric pressure which assists in the outgassing of entrapped air bubbles. In an effort to reduce microsphere breakage, the mixing speed of the internal paddles is 40 revolutions per minute. According to knowledgeable sources, a considerable quantity of microspheres can be shattered with improper mixing, which can reduce the deep water flotation by an excessive amount. Final mixing with the catalyst takes place outside the mix pot just prior to injection into the tubes.

Figure 10 is a schematic of the vacuum and pressurization system, illustrating the control valves and injection static mixer used to combine the catalyst with the microsphere-resin base. In addition to de-gassing the mix, the system controls top side pressurization of the two components, assisting in reducing the pressure drop created by the mixer tube shown in Figure 11.

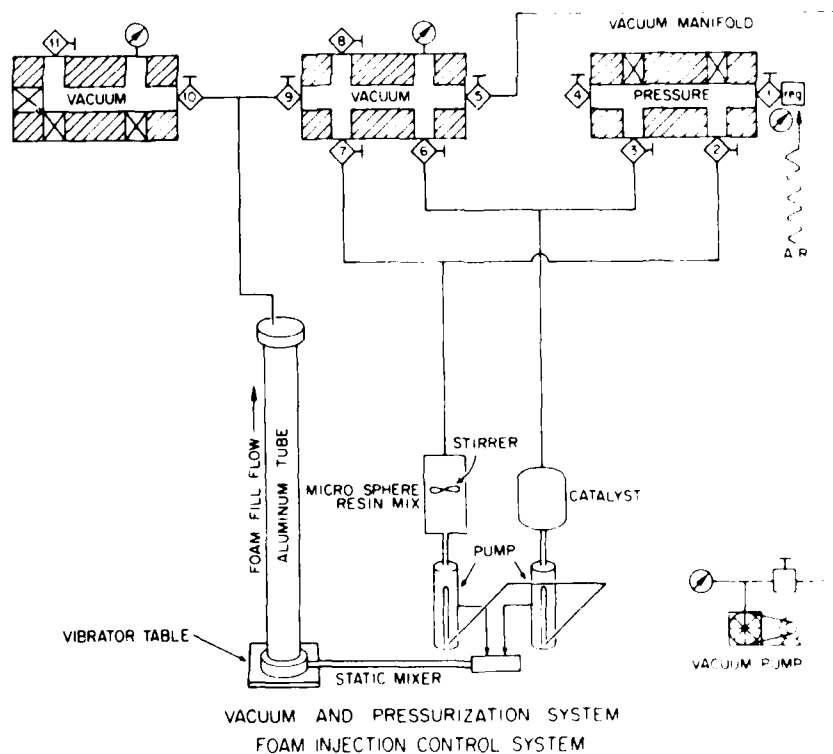


Figure 10a

The mixer is a static device that directs the incoming components radially toward the pipe walls, then back thru the element. By combining alternating right and left hand helix elements, reversal and flow division continues until a thoroughly mixed foam is ejected at the discharge end.

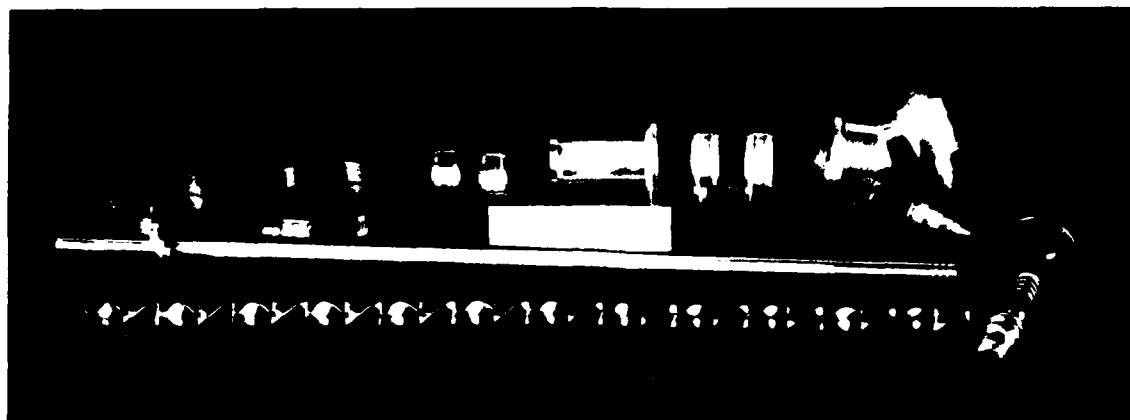


Fig. 11a. Static Catalyst/Epoxy Base Mixer Tube

The use of a mixer of this type allows the resin/microsphere mix and the catalyst to remain separated in their individual storage hoppers until the final instant in which they are combined at the inlet of the static mixer. The separate storage and end point mixing reduces the clean up necessary at the completion of a run. Inasmuch as the foam mix is a catalytically activated cure material, both the hopper and paddle chamber are able to retain unused material until a new batch is started. The only item of apparatus that must be cleaned before catalyst cure takes place is the mixing tube itself.

As shown in Figure 9, the tube is positioned vertically during filling. A table-type 110 volt, 60 cycle vibrator at the base of the tube assists in settling the mix as it is being pressure injected. A slight negative pressure is maintained at the upper end of the tube as a secondary assistance to reduce

the effect of static mixer pressure drop. The mixture has a room temperature viscosity of heavy batter, or approximately 3000 SSU.

From a standpoint of trouble free operation on the initial start up, the first injection run did not measure up to expectations; one could even conclude it was close to catastrophic. Several pressurized tygon (clear plastic) tubes came loose, extruding both catalyst and microsphere resin mix around the general area before system pressure could be reduced. The foam that was injected into the tube did not catalyze evenly throughout the tube bore, indicating either improper mixing in the static mixer, or more logically, an incorrect ratio of catalyst to resin from the variable ratio mechanical pumping system. The problem was investigated and several mechanical modifications put through the shop in anticipation of a second run.

At this time, the Versar Manufacturing Corporation approached the project office and expressed an interest in filling the 2 1/2 and 4 inch tubes with their deep water 38 lb/cubic foot density syntactic foam. Their sample runs were satisfactory, and the cost per pound of injected and cured foam was below the raw material and labor costs for in-house continuation of the program. Further effort on development of the in-house mixing apparatus was put on hold.

3.4 Rotary Carousel

The rotary carousel provides a means of moving the flume ducting and test section to a pre-determined position in relation to a magnetic north bench mark. The rotary track consists of two eight foot diameter aluminum 'I' beams as illustrated in Figure 12. The lower ring is secured to the flume ducting and test section, with the upper ring attached to the fixed exoskeleton.

Fig. 12a. Rotary Carousel and Recirculating Duct Assembly



The two rings are interconnected by three equally spaced trolley assemblies, one of which is illustrated in Figure 13. The wheeled trolley allows the lower ring and flume structure to be rotated 360 degrees. It is driven either clockwise or counterclockwise by a chain and sprocket mechanism that converts the linear travel of a hydraulic piston to a rotary motion.

A single hydraulic cylinder is mounted within the cheek plates of each trolley assembly. When carousel rotation has been completed, the three hydraulic cylinder piston rods extend, forcing the test section knife edge cookie cutter into the bottom sediment. The piston rod extension is fourteen inches. Figure 14 illustrates a typical insertion cylinder assembly in its fully retracted position.

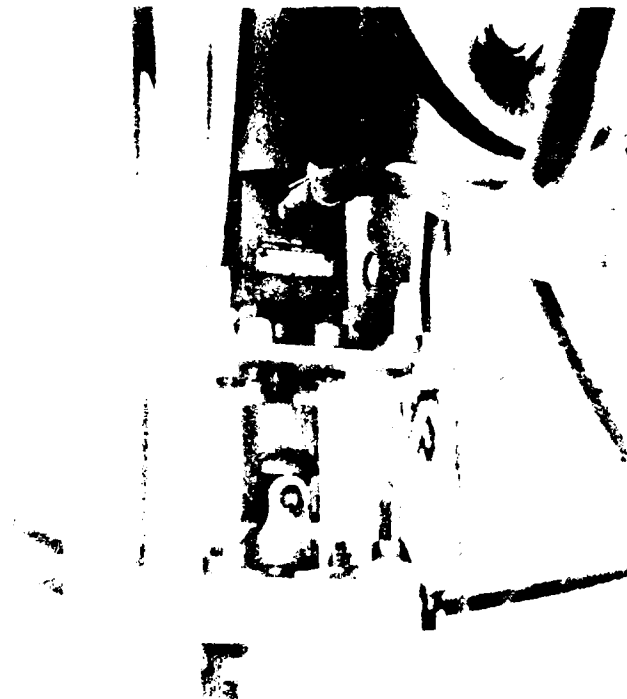
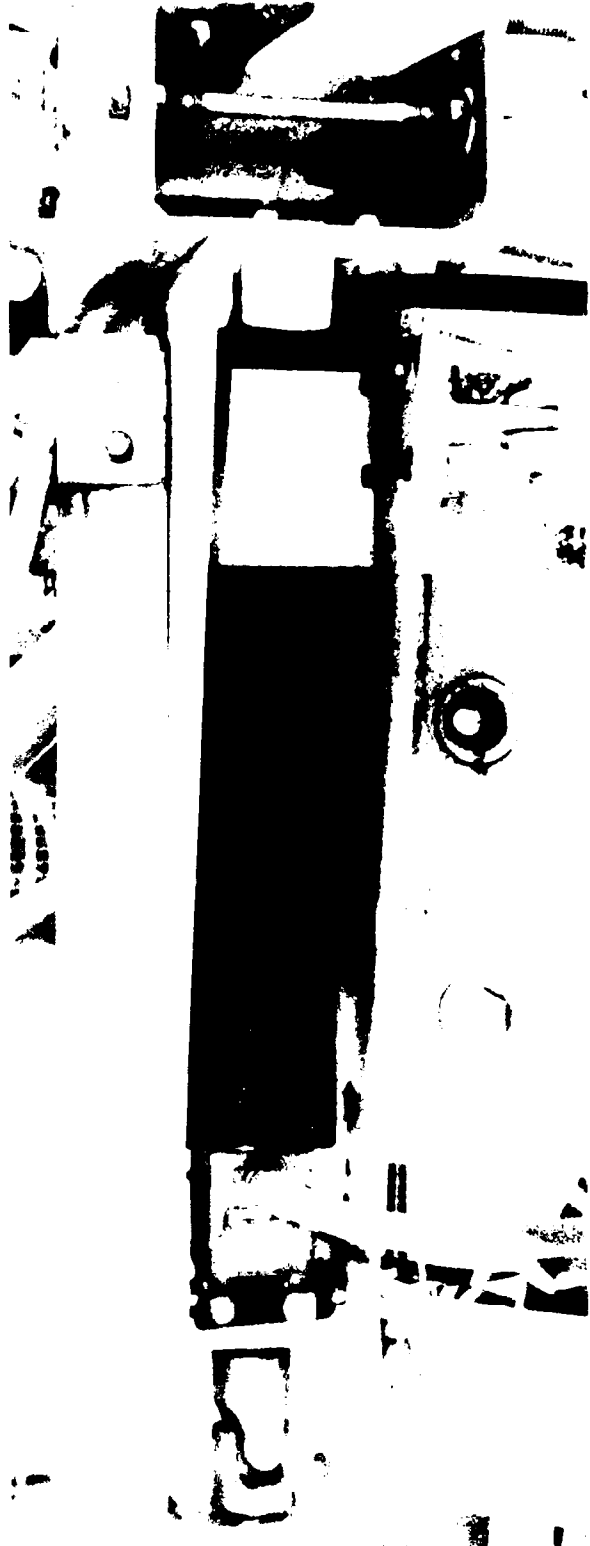
A slip joint alignment plate and a universal joint is secured at the end of each piston rod and attached to the aluminum ring as shown in Figure 15. Its purpose is to reduce the side load or strain on the piston rods and cylinder assemblies during the extension and retraction cycle. Despite the effort taken to align the two I beam rings, some eccentricity from the ring forming equipment does exist, and depending on the position of the bottom ring, a substantial side load could bind the piston rods during retraction. Figure 16 is a cross-section of the device.

3.5 Fibreglass Duct Work

The recirculation duct work was fabricated by both the wet lay-up method of fibreglass mat and cloth (brush coated with resin) and the use of a flock spray gun. The mat and resin was formed around wood and/or sheet metal plug forms. Figure 17 is an overall view of the preliminary assembly of several



FIG. 1. "P" Rear Track and Roller



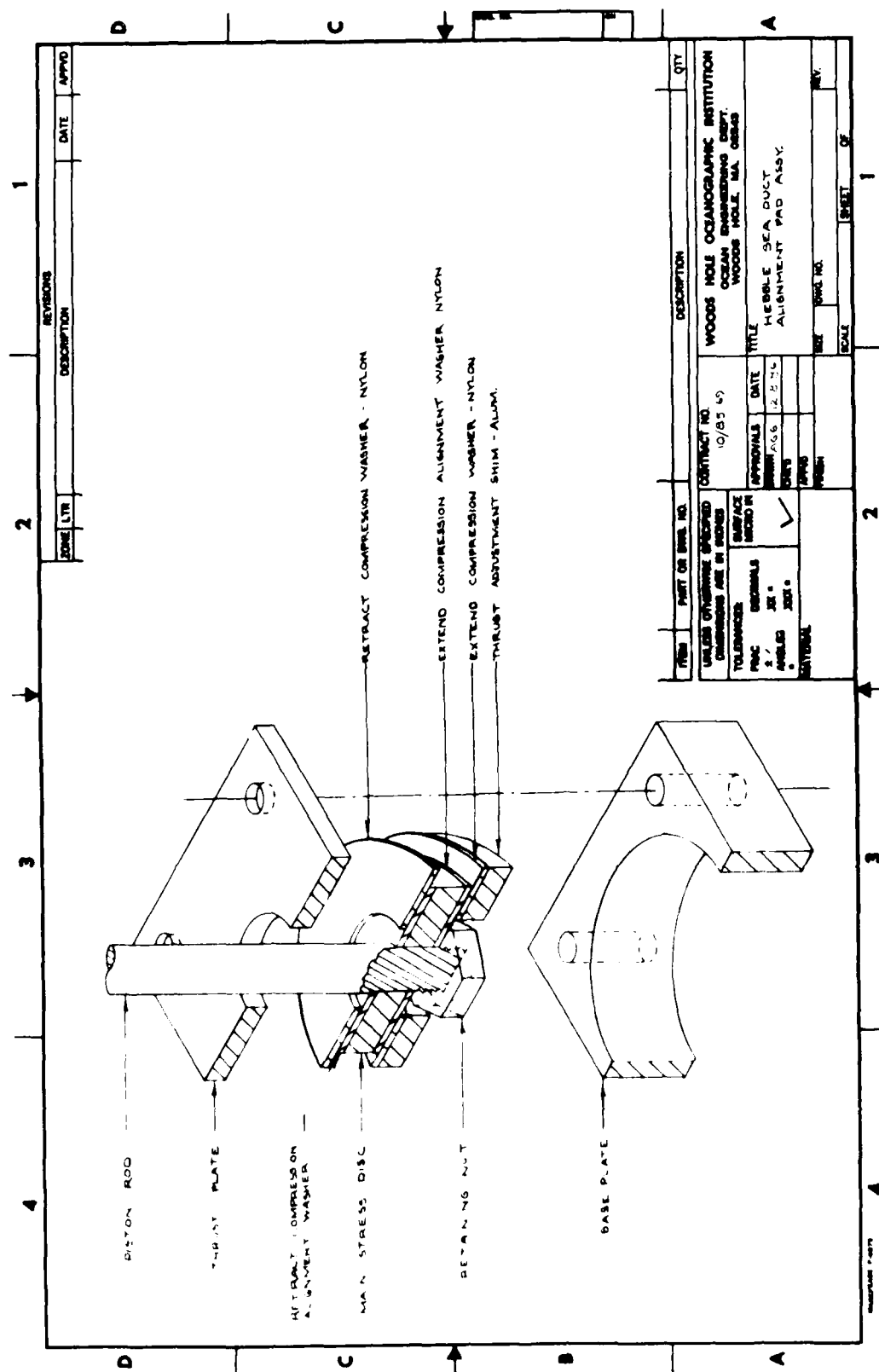


Fig. 16a. Slip Joint Cross Section.

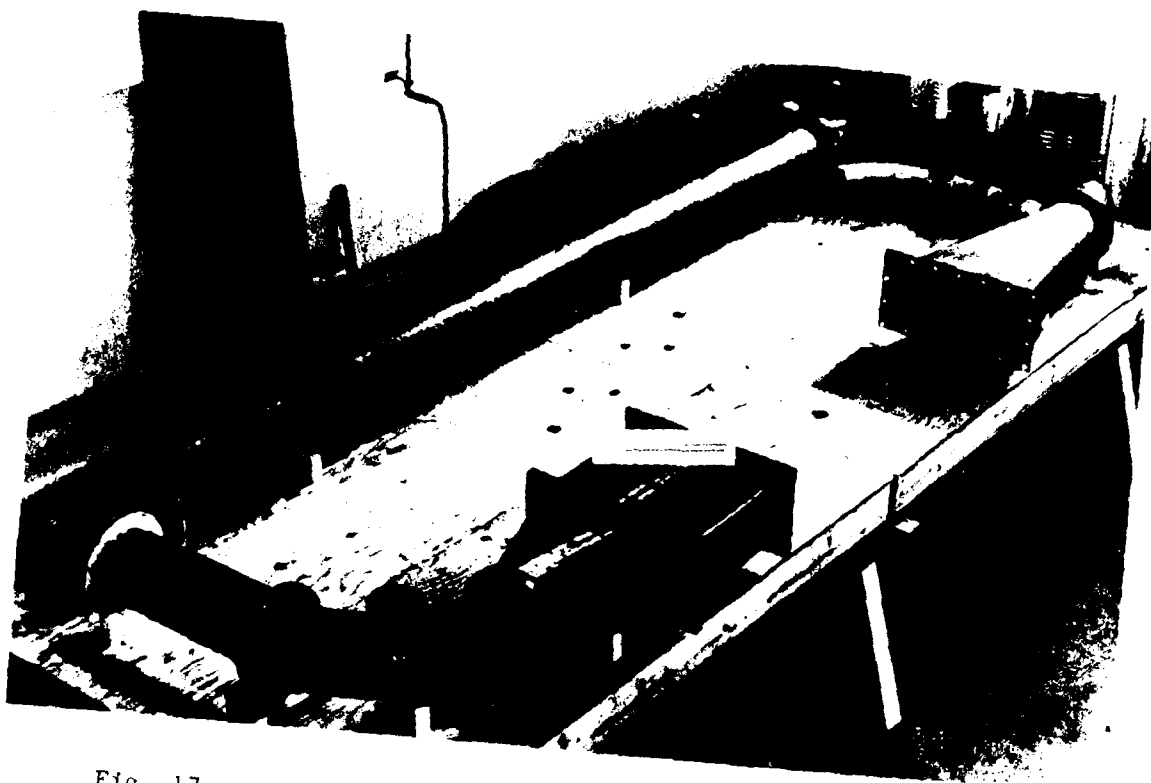


Fig. 17a. Preliminary Sections of the Recirculating Duct Work

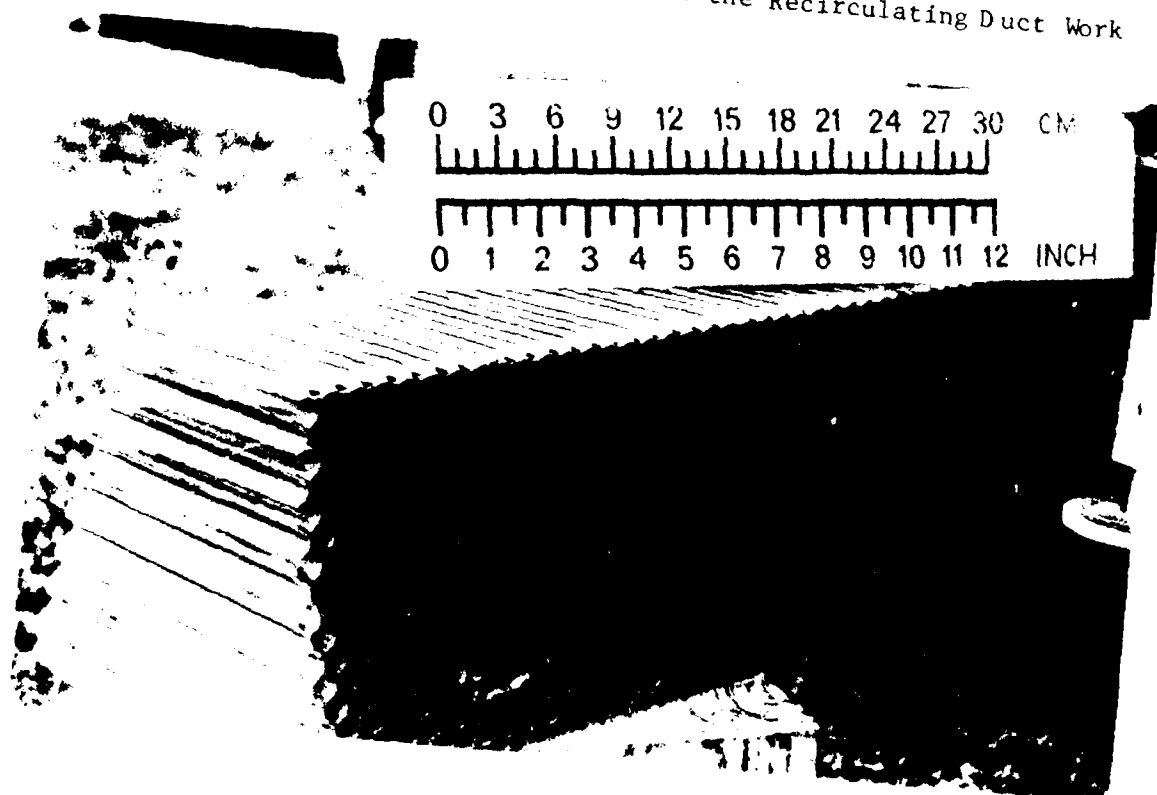


Fig. 18a. Honeycomb Plastic Flow Straightener

of the fibreglass sections. The rectangular truncated cone in the foreground is the transition section that allows the high velocity water in the eight inch I.D. tube to expand outward prior to entry into the rectangular section adjacent to the cone outlet. A plastic honey comb structure, or flow straightener (Figure 18), is located within this rectangular portion of the duct which will eventually be secured to the test section inlet. The flow strengthener is constructed with 1/4" passages, is 19 3/8" by 10" at the base, 8" high, and tapers to 5 1/2" at the top. The discharge end of the test section enters the wide end of the truncated cone at the right of the illustration. The convergent configuration forms a reasonably smooth transition for the fluid as it exits from the test section and re-enters the tubular duct work for recirculation.

The round hole at the top of the sweeping 90 degree elbow provides an entry and mounting point for an adjustable flow straightener vane, as well as the mounting pad for the vent and flood valve, one of which is illustrated in Figure 19. The vent and flood valves provide free venting of the test section

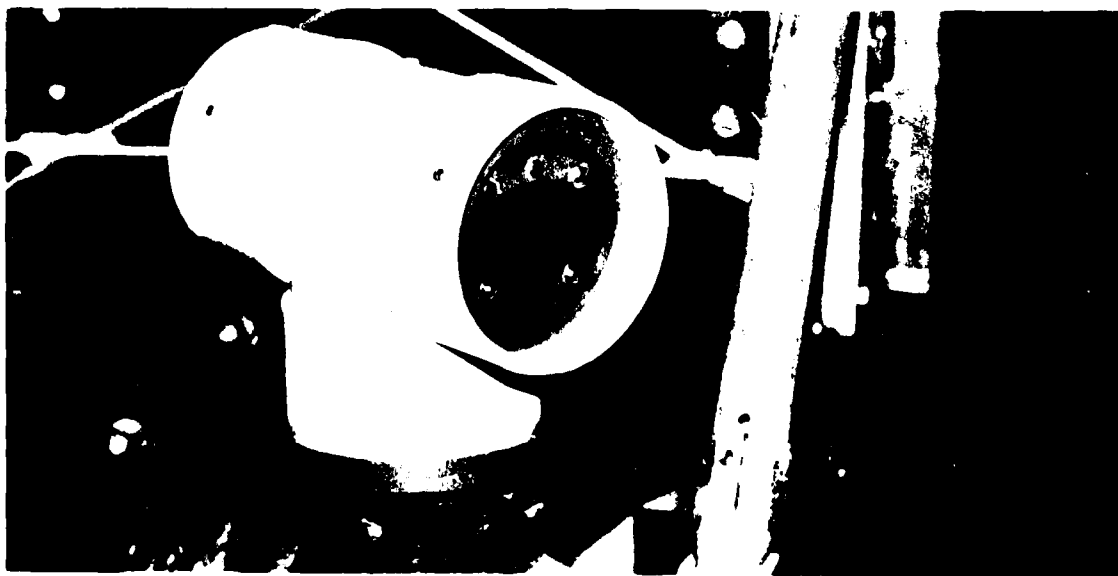


Fig. 19a

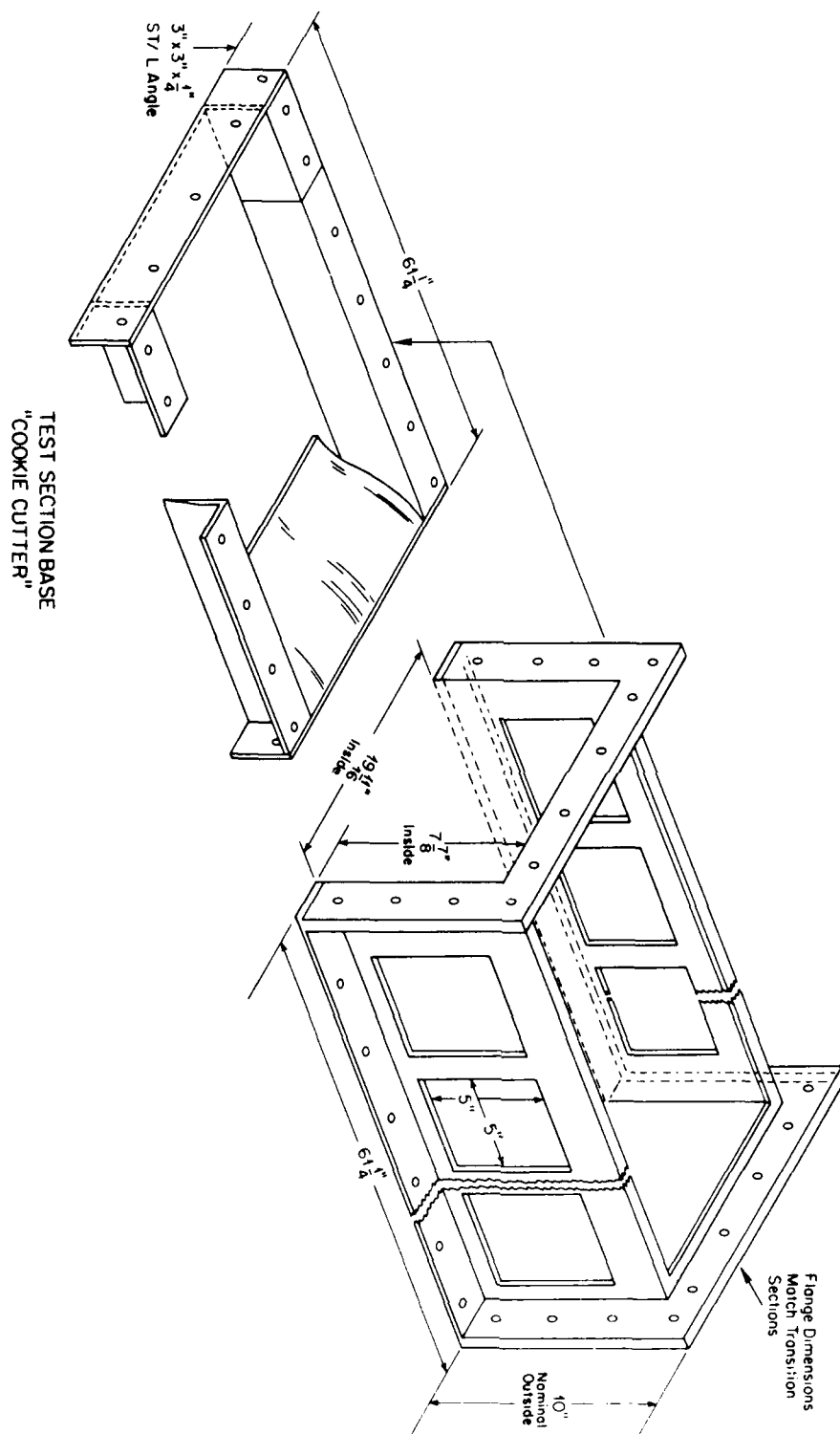


Fig. 20a. Design Concept of Test Section.

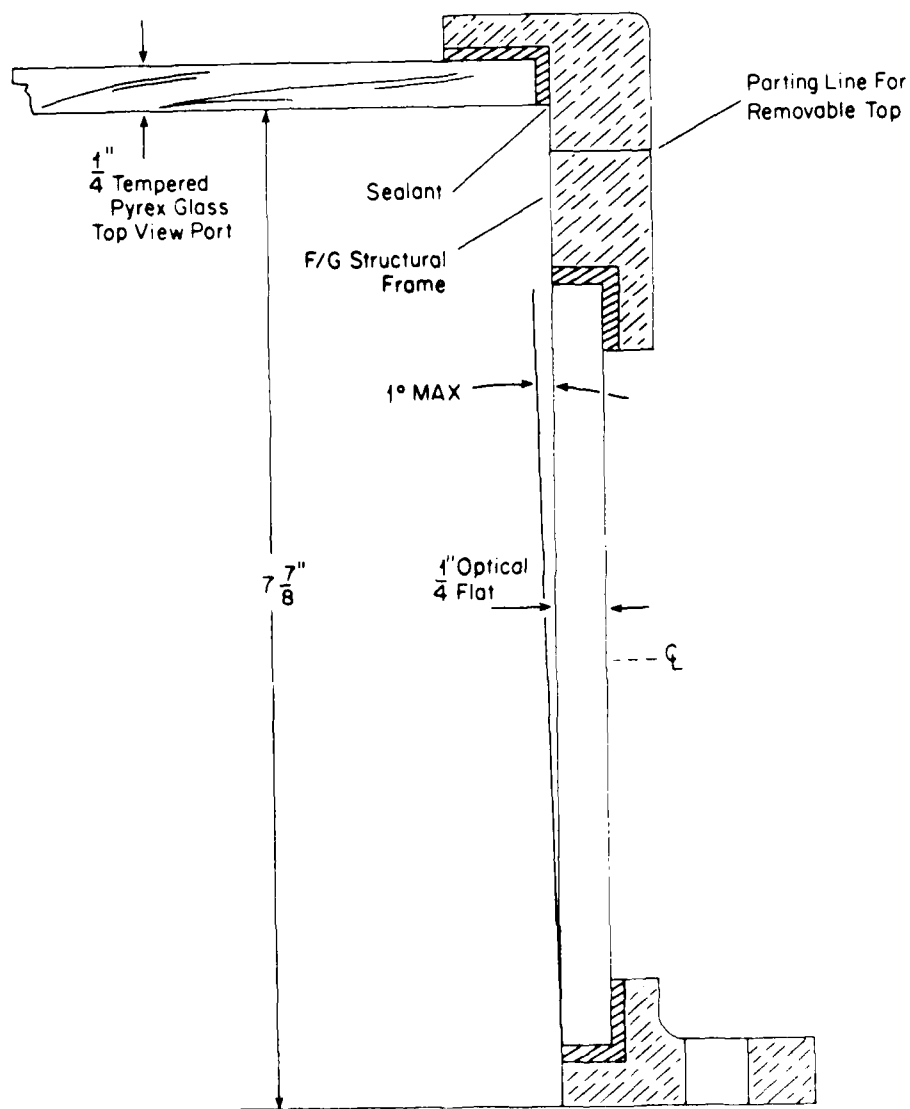
and recirculating duct work on initial entry through the air water interface. Inasmuch as the test section base is an opening with approximately eight square feet of area, the four vent tees reduce the internal pressure buildup that could pop the top plate glass section out of its frame. Conversely, on recovery they vent the system and reduce the possibility of pulling the glass panels out of their mounting structure.

The vent and flood valve design incorporates two round flapper plates secured to the plastic tee section with individual hinges. The seating surface on both the flapper and the valve body consists of rings of magnetic plastic cemented to their respective pieces. The flappers are weighted to assure closure after venting, while the magnetic plastic acts to maintain a closed position during internal circulation within the duck work. There are two flappers in each tee: one vents positive internal pressure, the other negative pressure. There are four valve assemblies on the flume, two at each end of the ductwork. The total venting area of a one direction flow is 33.4 square inches, which is equal to an open 7 inch I.D. vent pipe.

3.6 Test Section

The concept test section design is depicted in Figure 20. As noted in the end view, the internal dimensions are $19 \frac{11}{16}$ inches wide, $7 \frac{7}{8}$ inches high, with an overall length of $61 \frac{1}{4}$ inches from inlet to discharge. A 3-inch wide sharp edge stainless steel cookie cutter is located at the base of the chamber.

When the test section is inserted in the sediment to its normal operational depth, the internal test section height becomes $7 \frac{7}{8}$ inches. With the four knife edges of the rectangular cookie cutter completely sealed in the sediment, the flume becomes a closed loop recirculating system.



VIEW PORT CROSS SECTION

Fig. 21a. Optical Flat Side Port and Top Window Installation.

The material used to construct the test section frame was fibreglass mat impregnated with brush applied catalyst cured polyester resin, formed around a male mold. As the design progressed, some modifications were necessary to accommodate camera, flash, and test instrumentation mounting requirements. The internal dimensions of the test section remained as originally proposed, as did the top plate glass window and optical flat side ports.

The original flat plate cookie cutter was re-designed to become a 3-inch by 3-inch stainless steel angle, attached as the bolt-on assembly depicted at the lower left of Figure 20. The design change provided improved stiffness at the base of the test section, substantially reducing any strain that might be imposed on the optical flat side ports during sediment insertion.

There are eight optical flats located on each side of the test section. Each port is 6 inches square by 1/4 inch thick. They are secured in an elastomer adhesive and bedding compound as shown in the cross-section of Figure 21. The usable section of the viewport is 5 inches by 5 inches. They are flush with the inside surface of the test section and are oriented to be within one degree of maximum deviation off the vertical and horizontal planes formed by the inner walls of the chamber. All inner surfaces of the test section are smooth surfaced, with no protrusions to disrupt the fluid flow. The side walls of the test chamber were constructed to have no more than 3/16 of an inch total convergence or divergence from the inlet end to the discharge end.

The transition from flume structure to sediment is considered critical to fluid flow and sediment transport within the closed system. A method was devised to assure the test section inlet and discharge structure would always be flush with the sediment regardless of slight bottom undulations. A lead

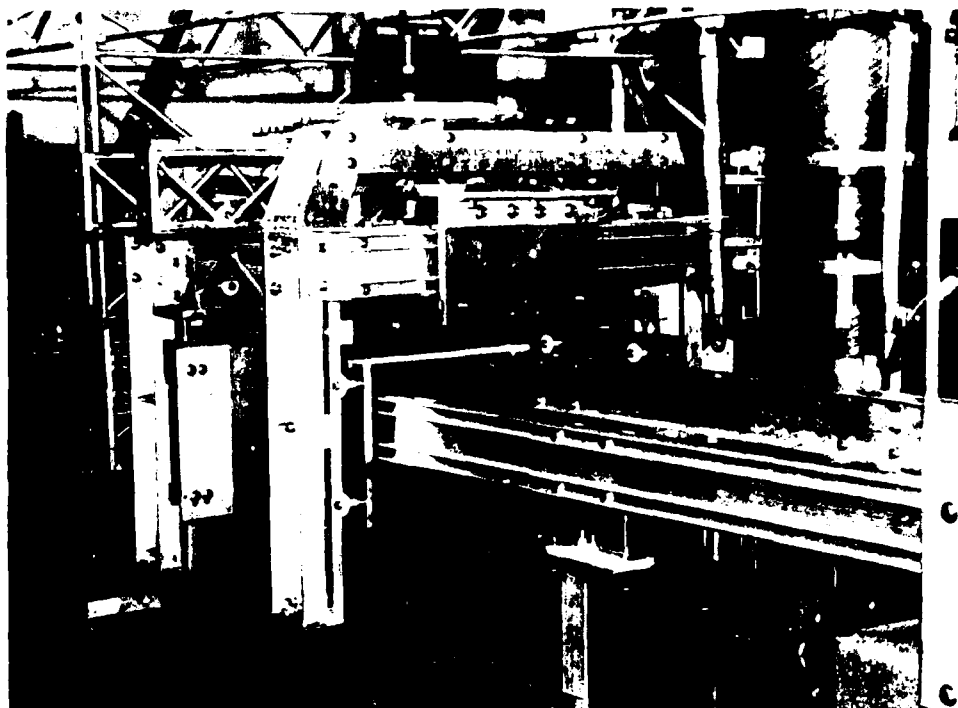


Fig. 22a. X-Y-Z Traverse Carriage

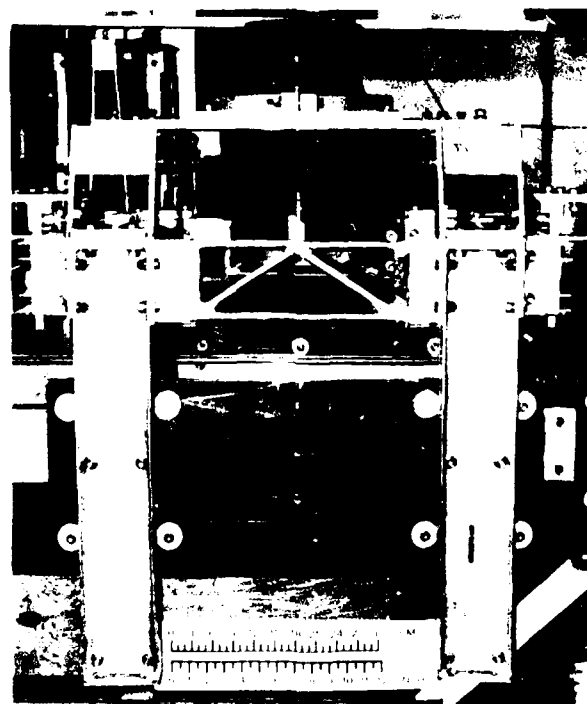


Fig. 23a. Carriage and Roller Vee Track Assembly.

impregnated vinyl sheet 1/16 of an inch thick was cut in strips 19 43/64 inches long by 6 inches wide. They were secured to the cookie cutter flange at both the inlet and discharge ends of the test section using high peel strength flexible epoxy.

In Figure 20, the artist illustrates a typical vinyl flap secured at the top surface of the cookie cutter. In use, the flexibility of the vinyl and the high density of the material resulted in the transition flap laying in near-perfect contact with the sediment, creating a smooth fluid flow from the duct work and flow straightener out across the sediment. A similar flap was located at the discharge end of the test section. Diver observation in shallow water tests, as well as sub-surface camera shots, substantiate that a smooth transition was obtained.

3.7 X-Y-Z Traverse Mechanism

The camera, flash, and laser Doppler velocimeter are mounted on a wheeled carriage assembly as illustrated in Figure 22. It traverses along a grooved track providing complete test section coverage along the 'X', or longitudinal axis. The athwartship, or 'Y' axis, and the vertical, or 'Z' axis motion is provided by two additional dollies appropriately positioned on the main carriage.

Each of the three linear motion tables are guided by triangular shaped nylon wheels that run in vee-groove tracks. To offset the wide variety of side load and positive and negative acceleration forces imposed on the carriage during ship pitch and roll and when passing through the air/water interface, the dollies are secured by dual sets of opposed rollers that prevent "track jumping". Figure 23 is a typical track and roller assembly.

The stereo camera and flash are secured to the 'X' traverse mechanism. Its motion is along the longitudinal axis only. The laser Doppler velocimeter transmitter and receiver are mounted vertically on the 'Y' and 'Z' axis tables, which are part of the main carriage. The three axis of motion allow the LDV to take measurements within the test section by taking 'slices' of the water column longitudinally, vertically and athwartship, or across, the water column.

All carriage and traverse tables are moved through the use of hydraulic cylinders. The 'X' axis is powered by one cylinder that has a 60-inch stroke. Positive mechanical stops in the form of piston rod sleeves are mounted within the cylinder, preventing carriage override and component damage. The 'Y' axis movement is performed by a single 15-inch travel piston assembly. It has internal extension and retraction sleeves that prevent override. The 'Z' axis (vertical motion) is performed by two cylinder assemblies having an eight inch maximum extension. They are mounted diagonally opposite on the vertical channels and the main carriage of the 'X' transverse table. The full retract position is the bottom stop. The upper stop is a set of four external adjustment screws that limit travel within the five inch height of the side viewport.

3.8 Recirculating Sea Water Pumping System

The original modelling flow tests were performed on a full scale recirculating flume in December 1982, by the Jet Propulsion Laboratory, located in Pasadena, California. Based on laboratory performance data, flume test section dimensions, tube run diameters, and pump power requirements began to emerge.

The recirculation pump power demand became the most dominant feature of

the Sea Duct design, as power availability was limited and would be time shared with other systems. Some thought was given to a modified aerospace fuel cell system presently in use on several NASA vehicles. Unfortunately, this did not become a realization, and the old standby lead-acid battery was resurrected.

A dual recirculation pump development program was initiated in an attempt to obtain the most efficient power consumption to flow ratio that matched the desired Sea Duct requirements. The proposed designs were a squirrel cage impeller and a conventional propeller system, both powered by 24 volt D.C. motor drives. Several pump manufacturers were contacted for information and advice; all were helpful and were willing to construct a suitable pump. Their schedule to complete the designs did not fit the Sea Duct program or budget. One pump engineer questioned, said: "Despite all our new computer knowledge, it's still a black art design problem that requires lots of sweat and tears before the pumps finally work." Enlightened by their words of wisdom, the designs went forward as rapidly as possible.

The first pump to be completed is shown in Figure 24. It was constructed of polyvinyl chloride (PVC) and consists of a squirrel cage impeller with an outer PVC scroll to direct the fluid through the tube run. The circular flange is the 8-inch diameter inlet and was sized to mate with the standard flange on the recirculating duct work. The square flange is the discharge port and mates with a transition piece as depicted in the upper right of Figure 25.

All bearings for the squirrel cage impeller were constructed in-house. They consisted of a molded TU79 polyurethane (soft elastomer) mixed with 2%

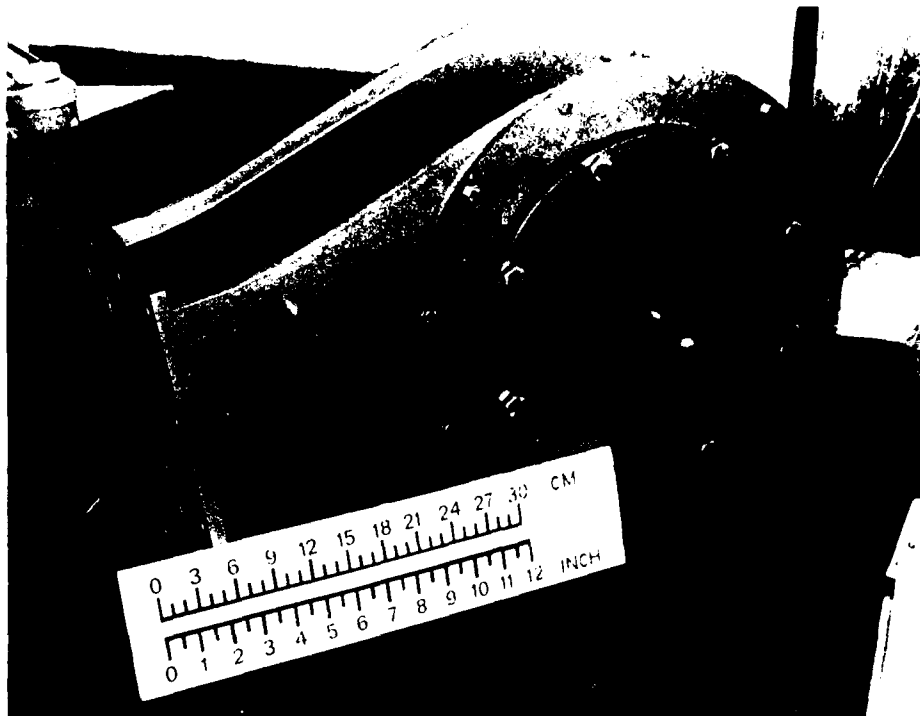


Fig. 24a. Squirrel Cage Pump

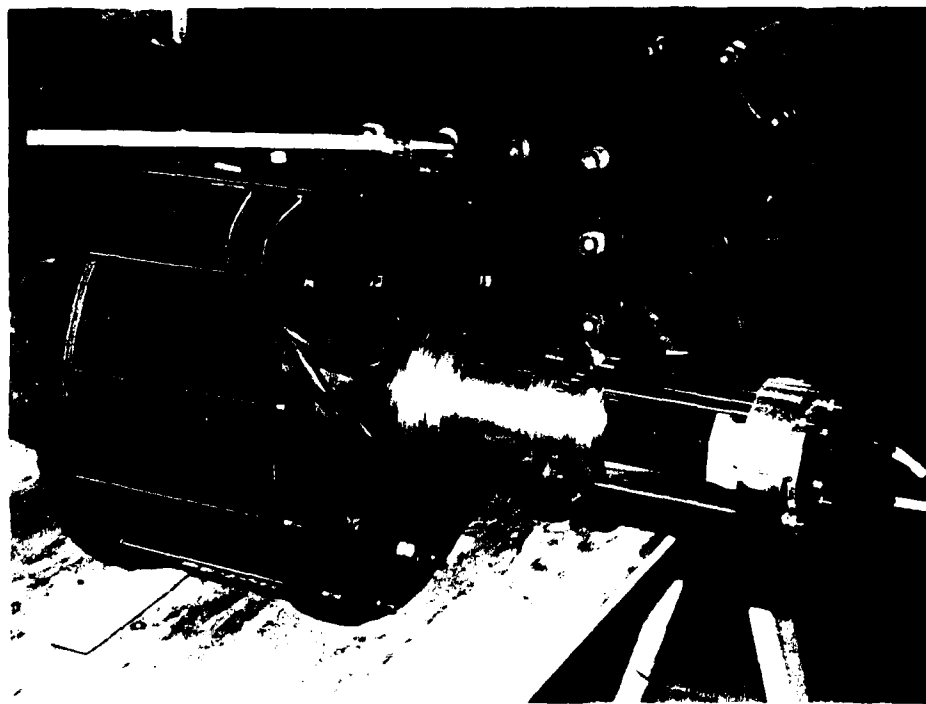


Fig. 25a. Squirrel Cage Pump and Pressure Compensated D.C. Drive Motor

by weight of flake graphite. The bearings are water lubricated by the fluid recirculating within the flume. They are patterned after a commercial elastomer marine bearing, have internal flutes, and are very resistant to silt bearing fluids.

The pump is mounted at the second 90 degree return elbow downstream of the test section. In this location it provides an 8-foot straight section of 8-inch tube to reduce fluid turbulence before entering the flow straightner honey comb section. Preliminary test runs indicated a flow velocity at the discharge end of the test section to be 0.75 knot. Current consumption was approximately 28 amperes.

Figure 25 provides a view of the pump drive mechanism. It consists of a commercially available, permanent magnet brush commutator motor that was modified for direct immersion in the sea water, and is pressure compensated by a variable pressure nitrogen system.



Fig. 26a. Propeller Driven Recirculating Pump Assembly



Fig. 27a. Lead Acid Battery Pack and Oil Compensated Housing

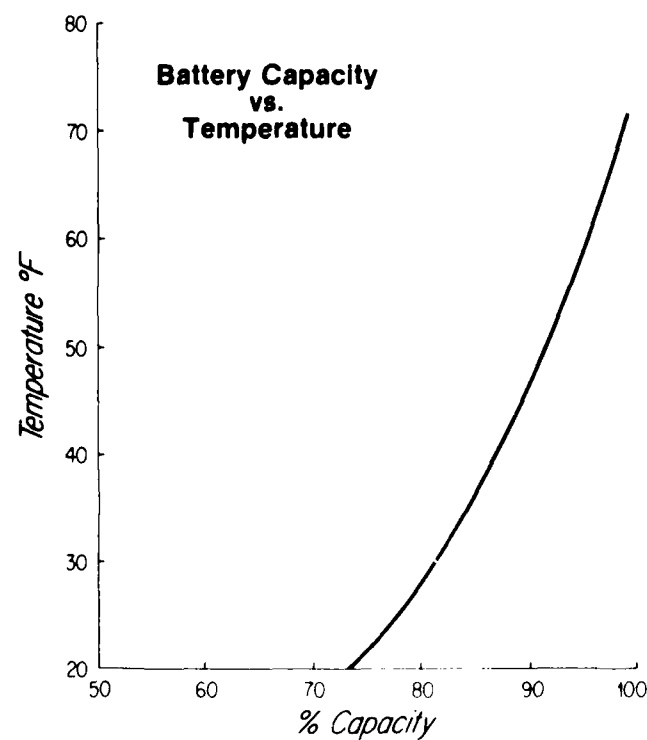


Fig. 28a. Battery Capacity VS. Temperature Curve

The second design consisted of a modified commercially available trolling motor (Figure 26). It required 12 volts D.C. as a power source, which did not readily adapt to the 24 volt battery packs. Several armatures were sent to rewind shops for modification. Testing of the reworked motors revealed they were marginal and prone to overheating and burn out.

Further marketing review uncovered a manufacturer that produced a 24 volt D.C. trolling motor. Several units were procured and modified for flow testing in the sea duct flume system. Initial evaluation indicated a test section flow at the discharge end was less than 0.5 knot. A second motor was installed upstream of the first pump; flow velocity through the test section with both pumps in operation increased to 0.9 knots. Power consumption at full thrust is approximately 18 amperes @ 24 volt D.C. input per motor. A microprocessor maintains control of the motor speed through the use of a variable pulse width modulator circuit, while pressure compensation of the two motors was provided by a common variable pressure nitrogen system.

3.9 Lead Acid Battery System

The raw power required to operate the recirculation system, hydraulic pump, and control relay coils is supplied by three separate banks of lead acid batteries. Figure 27 illustrates a typical 6 volt deep discharge battery, aluminum mounting rack, and the fibreglass oil-filled battery storage canister.

The EV-106 battery manufactured by Exide was selected to power the Sea Duct recirculating flume. Its past history of providing raw power for the Deep Submersible ALVIN has been superior. The polypropylene material used in

the construction of the outer case and top cover are compatible with MARCOL 52, a light mineral oil used for pressure compensation.

By design, each battery bank contains four batteries wired in series for a total output of 24 volts. Each battery is capable of providing 158 ampere hours. The three battery packs are wired in parallel for a total capacity of 474 ampere hours at 24 volts. During a deep water deployment the battery packs become cold-soaked, and while they do not actually lose their capacity, it is temporarily reduced as illustrated by the curve in Figure 28. Assuming a cold-soak at 34 degrees Fahrenheit, the 474 ampere hours are reduced to approximately 85% of its original value, or 402 ampere hours.

By virtue of lead acid battery discharge characteristics, standard safety practice dictates that the battery should not be discharged below 20% of its full charge. Assume full charge is 474 ampere hours: then 20% is 95 ampere hours of the charge that must remain in the stored energy system.

Using the original full charge value for the three packs wired in parallel, 474 ampere hours minus the capacity reduction due to temperature equals 402 ampere hours. Deducting the "must remain" charge of 95 ampere hours, the maximum usable capacity then becomes 307 ampere hours.

Assuming a maximum on the bottom operational deployment of five hours, the following ampere hour load schedule illustrates the energy level that must be supplied by the storage cells. All system mechanical traverse operations are provided by hydraulic cylinders driven by the hydraulic pump. Unlike the sea water recirculating system, the pump and power relays are intermittent users of energy. All control relays are pulse and latch devices and do not require current once they have been activated. As noted in the

load chart, all hydraulic valves require power to keep them in the activate position.

LOAD CHART

Hydraulic Pump Operation at 15.0 Amps	Minutes	Valve Activation at 4.8 Amps	Minutes
Rotate Flume	3		3
Insert Flume	8		8
X-Traverse	6		6
Y-Traverse	5		5
Z-Traverse	4		4
Sediment 1 Insert	2		2
Sediment 1 Retract	2		2
Sediment 2 Insert	2		2
Sediment 2 Retract	2		2
Retract Flume	8		8
Rotate Flume	3		3
Assume 11.25 Ampere Hours	45 Mins	Assume 3.6 Ampere Hrs	45 Mins

#1 Recirculating Pump operating 100% @ 18 amperes X 4.5 Hrs	= 81 Amp Hrs
#2 Recirculating Pump operating 50% @ 10 amperes X 2.0 Hrs	= 20 Amp Hrs
#2 Recirculating Pump operating 100% @ 18 amperes X 2.0 Hrs	= 36 Amp Hrs
Hydraulic Pump System	12 Amp Hrs
Valve Activation	4 Amp Hrs
Hyd. Pump Power Relay	1 Amp Hr
	<u>154 Amp Hr Load</u>

Available Stored Energy = 307 Ampere Hrs
 System Power Requirements = 154 Amp Hrs, or 31 Amp/Hr Discharge Load for 5 Hrs
 153 Amp Hrs Remain for Contingency

Referring to the line illustrated in Figure 29, the available capacity of a single EV-106 battery in minutes of discharge VS. a fixed load, reveals that a system load of 30 amperes could conceivably be sustained for 350 minutes (5.8 hrs). The three Sea Duct battery banks are wired in parallel providing 350×3 , or 1050 minutes (17.5 hrs) of operational bottom time.

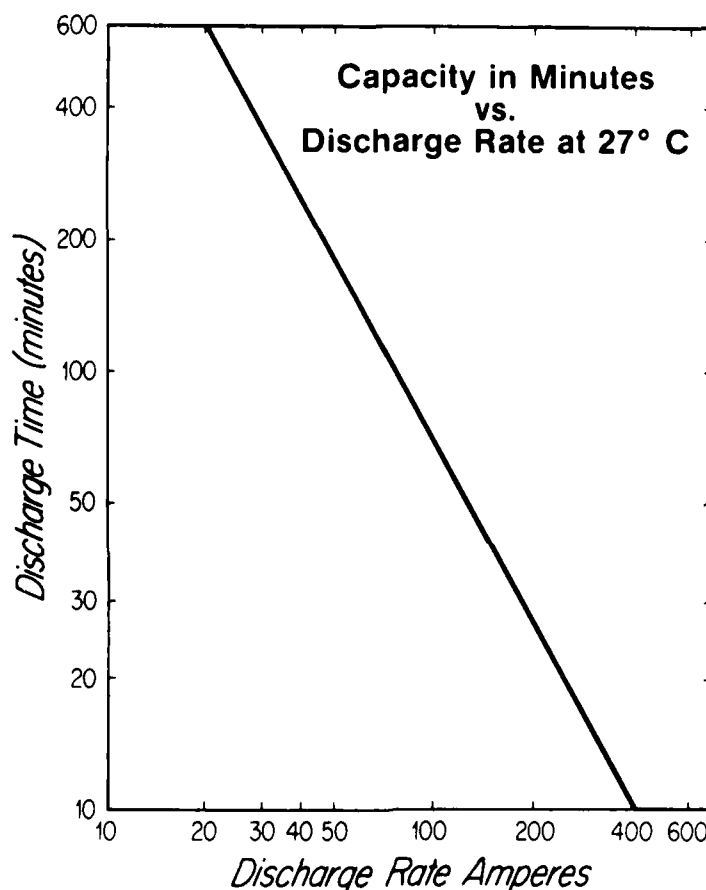


Fig. 29a. EV-106 Battery Capacity in Minutes VS. Discharge Rate Curve

To isolate the individual battery packs and to prevent low cells from drawing energy from those with higher potentials, a Motorola MBR-7545 Schottky Diode, 75 amp @ 45 volts is wired in the positive lead of each bank. Unfortunately, the diode construction is incapable of resisting the hydrostatic crush pressure at the 5000 meter depth, and as such, required installation in

a pressure resistant housing. Figure 30 shows the rectangular aluminum pressure case used to protect the three diodes. The diode block is mounted in the main battery power relay canister, and is part of the circuits controlled by the three mechanical latch relays shown in the photograph. The individual relay contacts are wired in parallel and have a conservative rating of 40 amperes per battery pack.

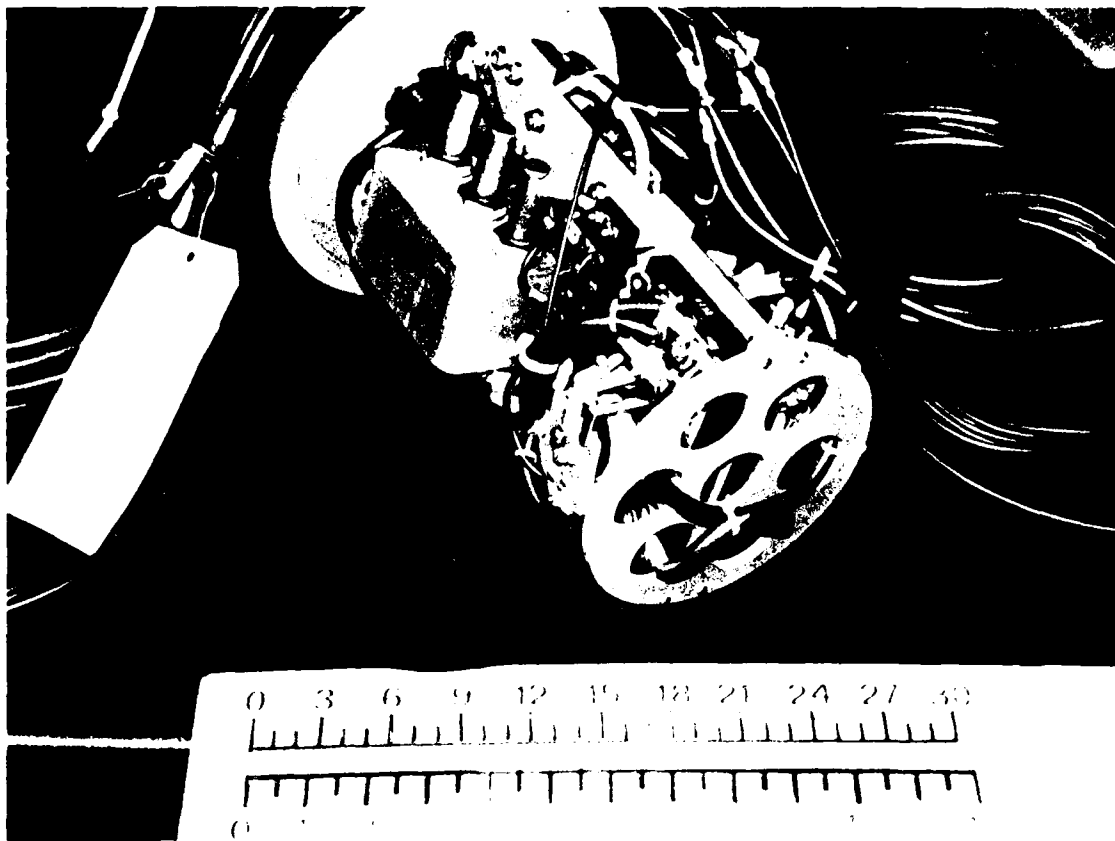


Fig. 30a. Isolation Diode Pressure Housing

As a point of interest, both positive and negative power leads, all pump motors, relays, and hydraulic solenoids use a closed loop wiring system. No part of the Sea Duct structure, X-Y-Z traverse table, or pressure resistant housing is used as a ground or common return line. By design, all electrical circuits are both isolated and insulated from the Sea Duct structure.

3.9.1 Battery Compensation System

The upper battery canister shown in Figure 31 illustrates a typical top hat pressure compensation bladder installed at the base of each battery pack. It consists of a welded polyvinyl chloride tube, end flanges and two top hat flexible bladders molded from TU-79, an amber colored catalyst-cured polyurethane material. The elastomer appears to have excellent resistance to sea water, MIL-H-5606 hydraulic fluid, and MARCOL 52, a light viscosity mineral oil. Individual bladders have been in direct contact with the two oils for periods up to one year with no noticeable degradation. A two-year exposure to direct sunlight appears to have caused a crystalline sub-surface appearance in the elastomer, although its flexibility has not been impaired and no leaks or cracks have been observed.

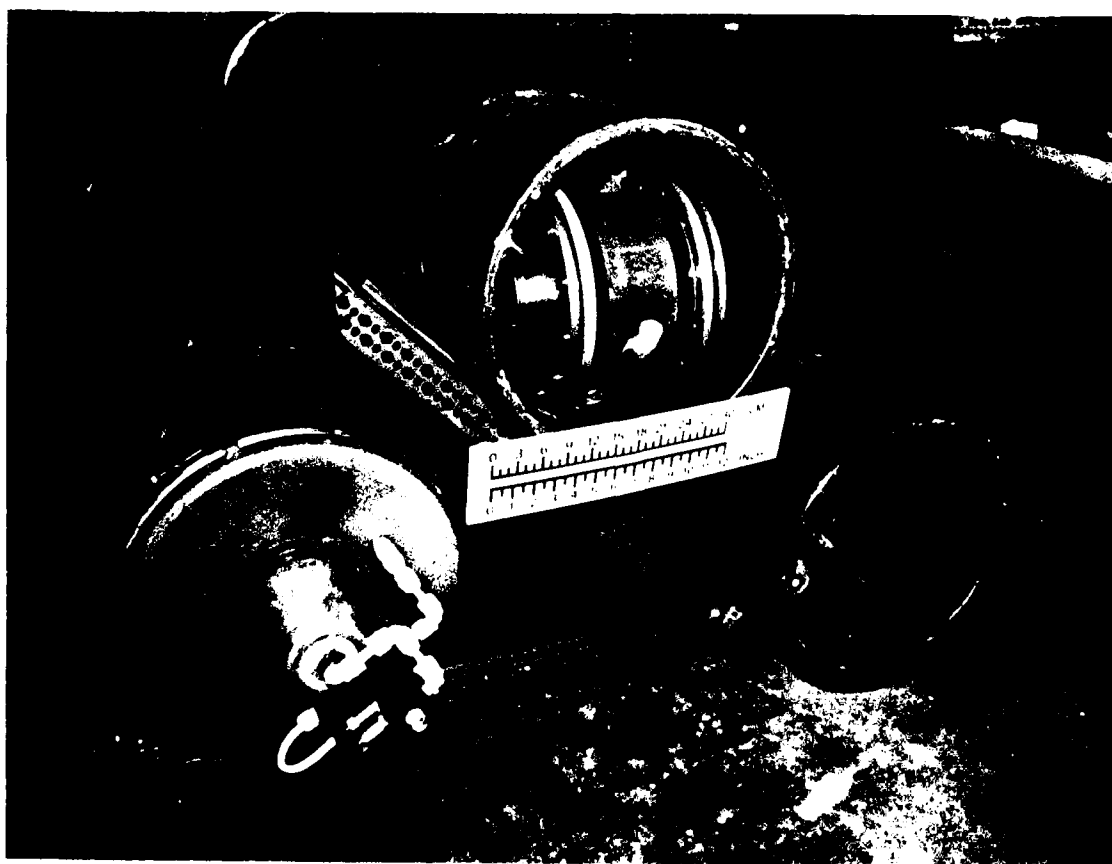


Fig. 31a. Battery Canister and Top Hat Compensation Diaphragm

The basic compensation schematic is illustrated in Figure 32. The various anti-siphon check valves prevent back-flow of the MARCOL 52 fluid into the flexible reservoir when the surface vent hose is installed. They are instrumental in preventing the inrush of air and hydrogen gas into the oil-filled disconnect. The relief and check valve manifold prevents sea water from entering the system during descent, and provides gas venting during ascent. The small oil-filled bladder compensation and water trap is positioned below the quick disconnect and directs any water leakage away from the electrical pins and into the trap where it can be immediately seen and removed.

The conical protuberance on the top cover plate (Figs. 31 and 32) houses the hydrogen gas bubble breaker assembly. Figure 33 is a cross-sectional sketch of the device. When gassing occurs in oil compensated lead acid battery systems, the individual cells burp at a rapid rate as the system returns to the surface. The gas collects at the top of the battery pack, continues to expand, and if not broken up into smaller bubbles, tends to push substantial slugs of oil out the vent valve. This loss of fluid continues until the volume is reduced below the storage capacity of the compensation bladder. At this point, compensation is essentially lost and structural damage and water intrusion becomes a strong possibility.

Referring to Figure 34, the inner construction of the bubble breaker consists of mesh discs of polypropylene mist eliminator material manufactured by Kimre Incorporated. Perforated discs of neoprene elastomer direct the gas/oil mix through numerous changes of direction, slowing the flow and squeezing the bubbles into a fine "fuzz" as they reach the top of the tower. Entrained oil is returned via the central stand pipe, while the gas is vented at the exit and through the relief valve manifold.

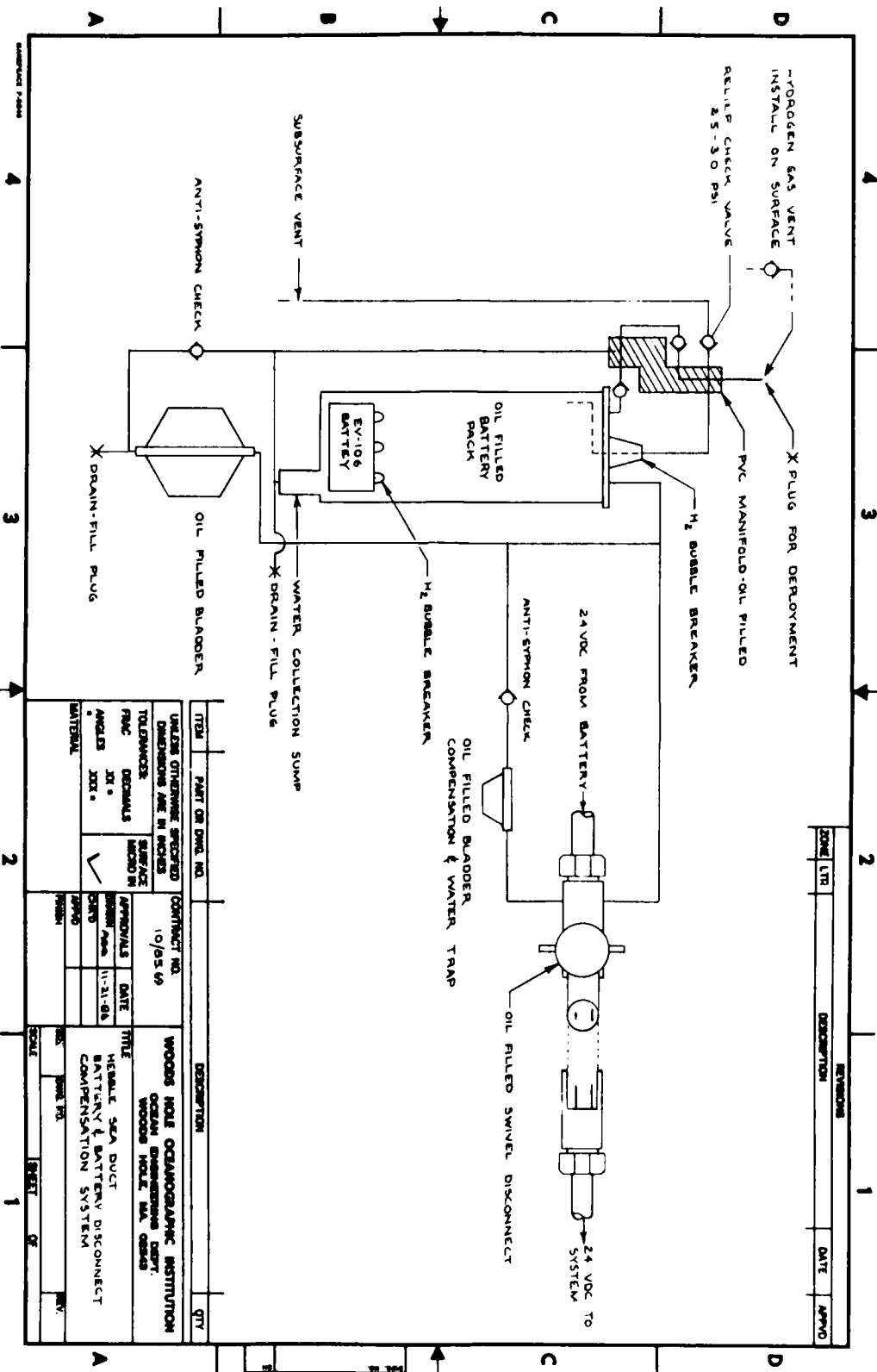


Fig. 32a. Battery and Battery Disconnect Compensation System

During the vent cycle the relief valve opens, venting the hydrogen gas to sea water. Unfortunately, most relief valves allow a small quantity of water to leak back into the system during the crack, or dribble, stage. To avoid having sea water drain on the battery covers, a flexible hose is attached to the base of the vertical stand pipe oil return, directing any water to the drain sump at the base of the battery pack canister.

A smaller version of the bubble breaker is used on the individual cells of the lead acid batteries. In this application, it reduces the entrainment of electrolytes as the hydrogen gas expands and burps through the filler plug and into the compensating oil.

At-sea operational experience and end of season disassembly has shown the bubble breaker design on both the batteries and main battery pack vent are working satisfactorily. Actual at-sea and off the dock deployment show a minimum oil slick; this includes recovery from a 5000 meter deployment.

The small quantity of compensation oil that is required for topping off the system prior to re-deployment is minimal. It is estimated to be 1 to 3 quarts, indicating a minimum loss during the gas burp cycle. Disassembly inspection of the batteries, battery rack, and electrolyte level substantiate the fact that the electrolyte is being satisfactorily retained in the battery cells.

3.9.2 Battery Breakaway Disconnect

The three DC battery packs are designed as part of the last resort emergency recovery mode. They are base mounted on an off-center pivot point that allows them to drop away from the external frame when placed in the emergency release mode.

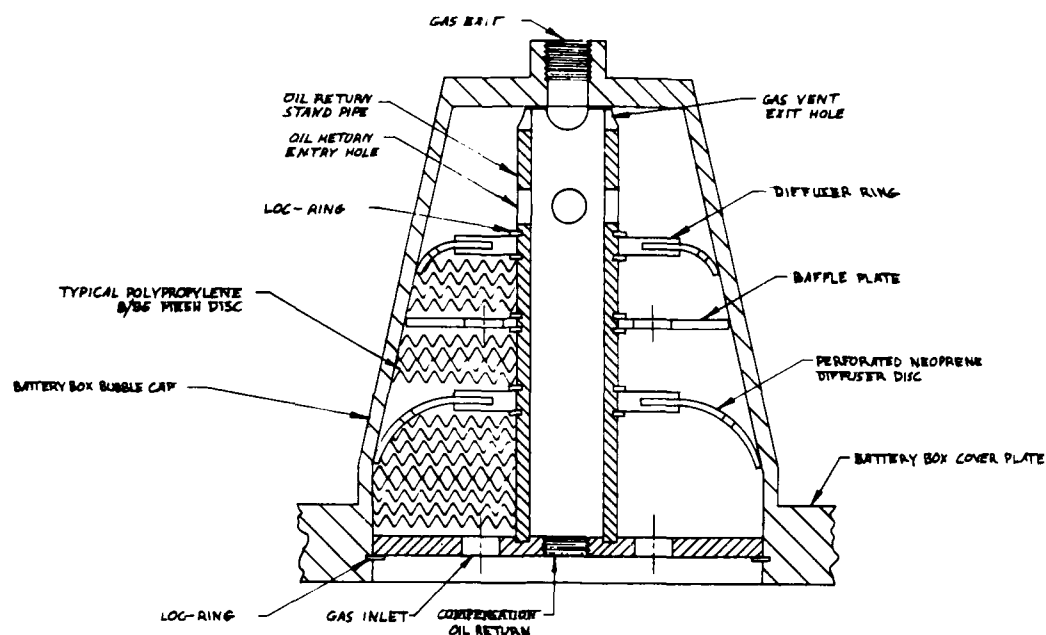


Fig. 33a. Cross Sectional Sketch of Hydrogen Gas Bubble Breaker Assembly

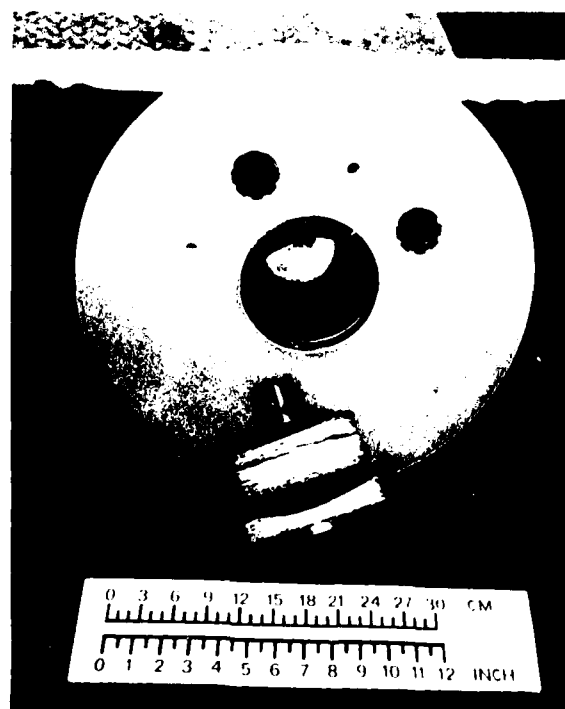


Fig. 34a. Polypropylene Mesh Bubble Breaker and Stand Pipe Return

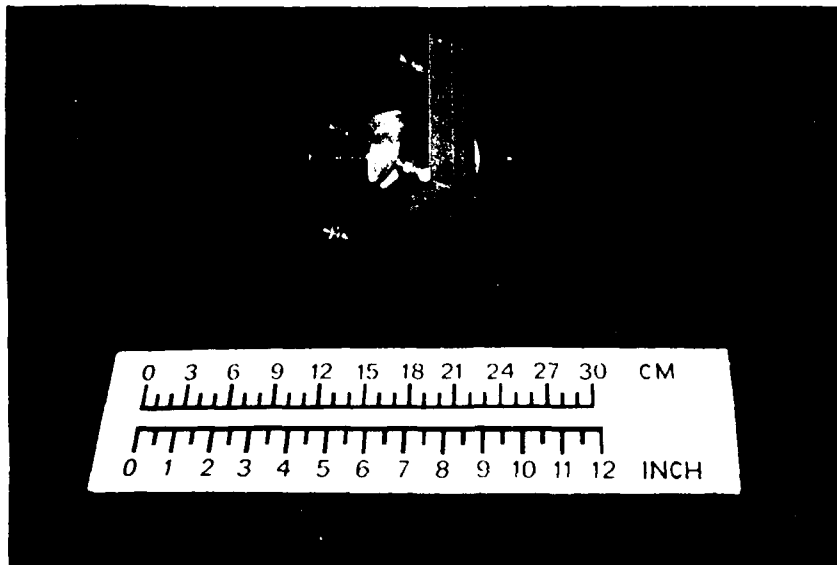


Fig. 35a. Free Swivel Electrical Disconnect

To assure a clean breakaway of the main power leads, the self-aligning, free swivel electrical disconnect illustrated in Figure 35 was designed. It consists of a modified stainless steel disconnect coupling manufactured by the Hansen Manufacturing Company, an Amphenol Company pin and socket electrical connector, and a 3-inch diameter plastic ball floating between two PVC plastic end plates. Figure 36 is an exploded view of the components.

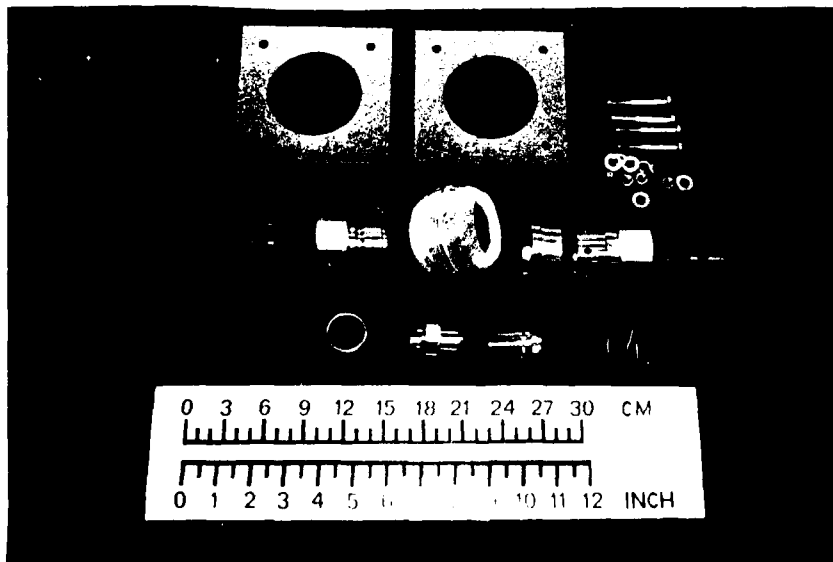


Fig. 36a. Exploded View of Disconnect Components

The pin and socket configuration is keyed, preventing inadvertent electrical short-circuiting during mating of the connector. The disconnect pin and socket rating is 70 amperes; the breakaway pull to separate the two sections is less than 12 pounds.

To assure breakaway and to eliminate any pressure differential between the external sea water and the internal portion of the assembly, the device is oil-filled and pressure compensated. The balanced oil pressure prevents "locking" of the disconnect at deep depth. Figure 37 is a cross-sectional view of the disconnect in the mated condition.

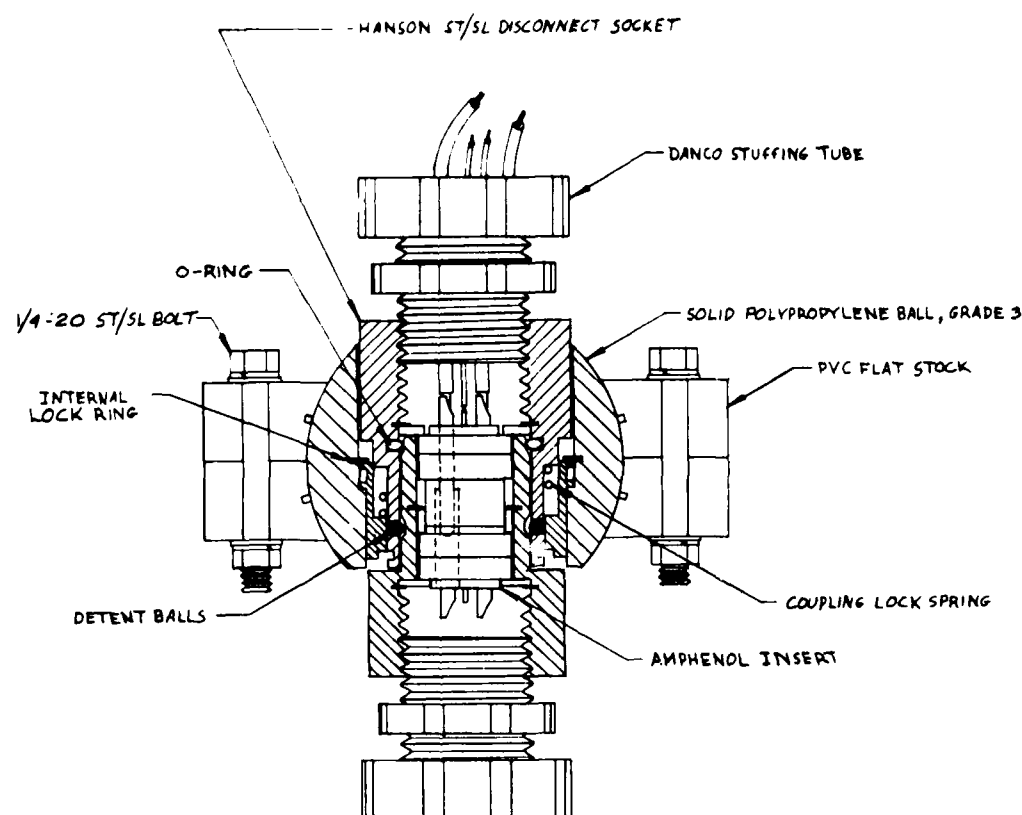


Fig. 37a. Cross Section of Battery Disconnect.

4.0 Nitrogen Bootstrap Compensation System

The Nitrogen Bootstrap System was designed as a means of providing a method of pressure compensating an electric motor by using a sea water pressure intensifier operating on a gaseous medium. By using a free floating piston, the compensating gas is continuously compressed to a pressure above that of the outside water column. It is capable of operating at extended sub-surface depths, and is depth limited only by the volume of the initial gas charge within the intensifier accumulator.

The gas compensation method is an experimental attempt to eliminate the use of dielectric fluid as the compensating medium, and assist in reducing the windage loss resulting from the fluid density and viscosity variations that are associated with decreasing temperatures and increasing pressure depths.

4.1 Background Development of Pressure Compensation Requirements

The use of limited horsepower (3/4 and lower) direct current brush type electric motors in submerged applications requires the use of pressure resistant heavy wall motor housings and armature shaft seals that allow thru hull penetration, while preventing salt water intrusion. This dry atmospheric pressure approach is a satisfactory method for shallow water applications.

Unfortunately, as depth and pressures increase, the shaft seal integrity becomes a problem. Leakage and friction forces gradually increase until seal failure or motor stall occurs. Existing shaft seals can be obtained for operational pressures in the 1500 PSI range, or approximately 3,500 foot water depth. The break-away and running torque of seals of this type absorb a high percentage of the available torque, substantially reducing the output

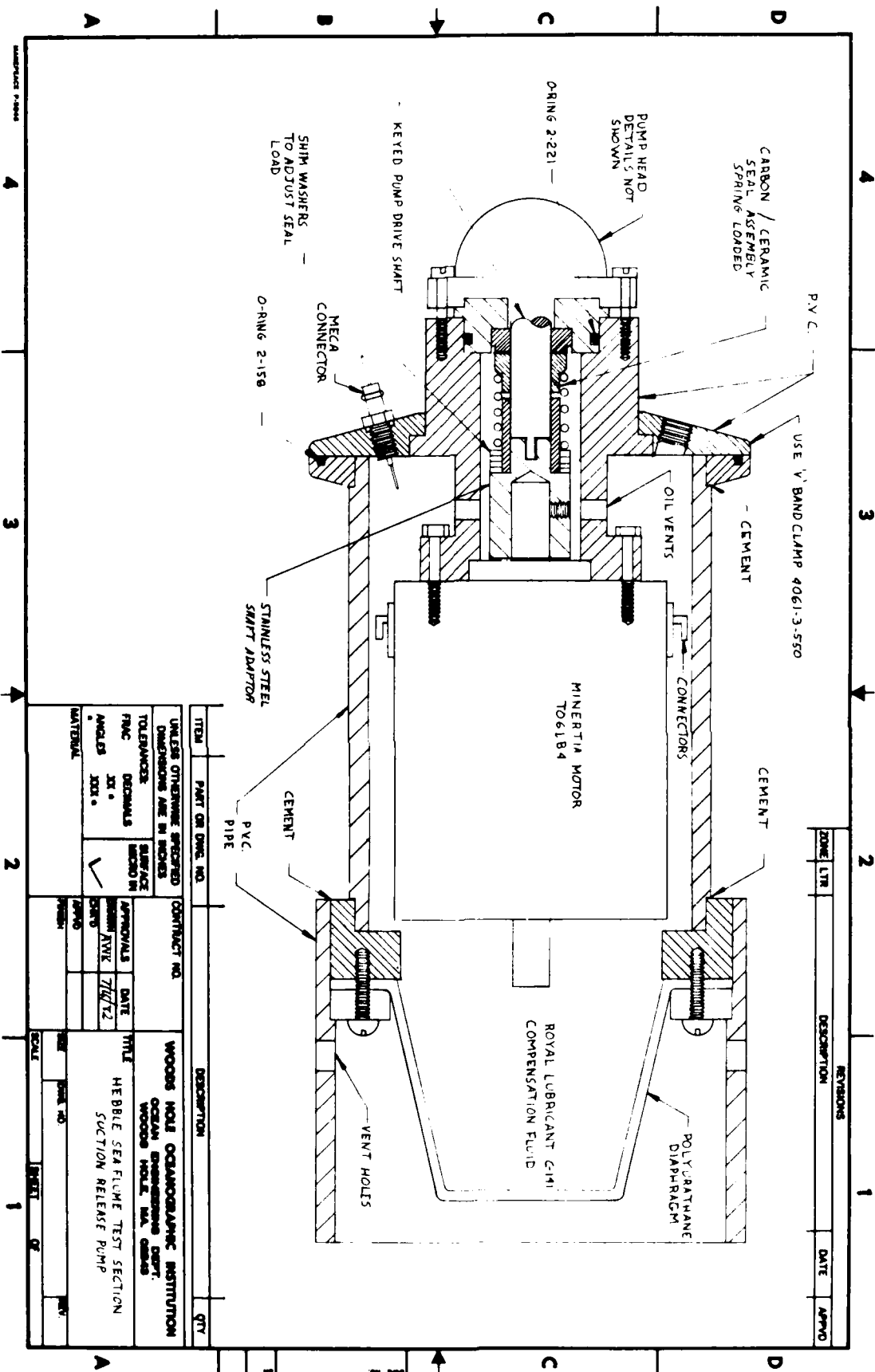


Fig. 38a. Cross Section of Typical Oil Compensated Motor Assembly.

of a limited HP motor. The use of small 'dry' motors at the deeper ocean depth is extremely undesirable due to shaft seal problems and housing wall thickness requirements.

The second, more prevalent method, is to use thin wall motor housings with low friction, low pressure carbon/ceramic face seals, elastomer and plastic O-rings, or even lip seals to prevent salt water entry at the shaft penetration area. To prevent collapse of the thin wall housing it is filled with a light weight dielectric fluid. A flexible diaphragm is attached to the housing, providing a means of transferring the outside sea water pressure to the inner fluid. During deployment, the external pressure increases as the device descends through the water column; the fluid contained within the motor housing also increases in pressure due to the forces transmitted through the flexible diaphragm. In essence, the device has become a pressure-balanced system. Figure 38 illustrates a typical oil compensated motor assembly.

In operation, the oil provides some resistance to the rotating armature as it 'pushes' its way through the fluid. The motor also requires an increase in brush spring pressure to break through the oil film at the commutator segments. The increased spring pressure results in accelerated brush and commutator wear. Brush carbon particles (commutator copper dust and the by-products of fluid submerged electrical arcing), or fluid burning, gradually increase the contaminant level in the compensating fluid until the dielectric properties are substantially decreased. The end result is commutator shorting by conductive bridging, or even direct shorting of the wiring within the motor proper.

Dielectric fluid pressure compensation is a viable and frequently used method of operating brush commutated D.C. motors at extended ocean depths.

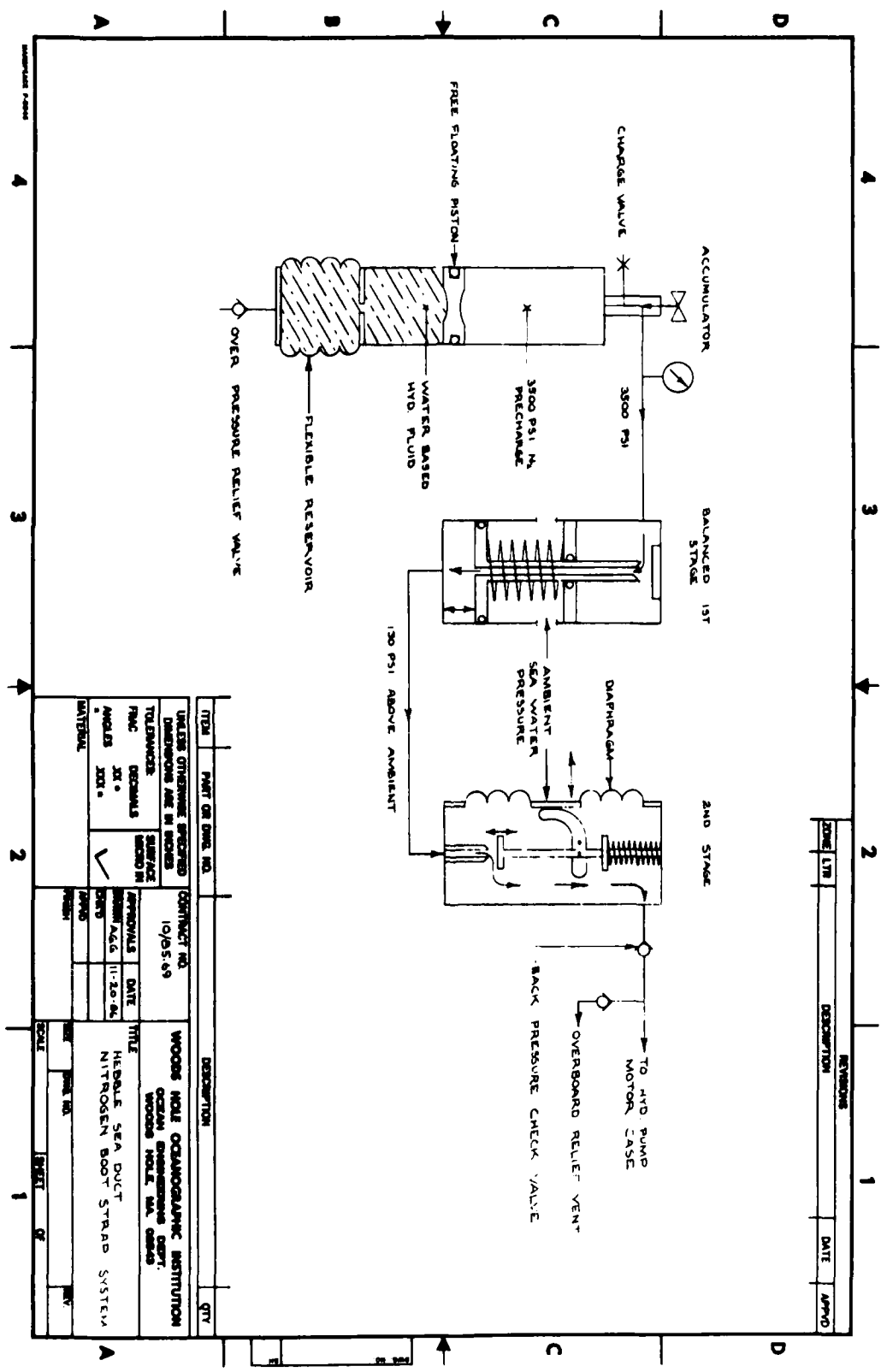


Fig. 39a. Nitrogen Compensation System Schematic.

It does, however, require frequent inspection periods, careful maintenance, and low voltages to assure a minimum of brush arcing. Some experimentation may be required in the selection of a brush material, as some compounds have been known to become mushy and disintegrate in the compensation oil.

4.2 Nitrogen Bootstrap System General Description

The device to be described is illustrated in the system sketch Figure 39. It consists of a high pressure accumulator with a free floating piston separating the water base hydraulic fluid from the nitrogen gas. A first stage piston-type pressure regulator reduces the accumulator charge to 130 PSIG above outside ambient sea water pressure.

A second stage diaphragm regulator maintains the final nitrogen discharge pressure at 0.2 to 0.3 PSIG above outside ambient. A set of check and relief valves direct the nitrogen compensation flow to the motor housing. The back pressure check valve prevents diaphragm rupture as the motor housing pressure rises above outside ambient during the ascent phase. When the motor housing pressure reaches a pre-selected value, the overboard relief valve vents. The over pressure relief on the fluid filled reservoir vents any excess pressure on the hydraulic fluid side in the event of piston seal weepage. It is important that the back pressure check valve have a low crack pressure to assure the motor case compensation pressure does not lag behind the actual outside ambient sea water pressure.

4.3 Nitrogen Charge and Operational Compensation Cycle

Referring to Figure 39, the system is initially charged through the nitrogen fill valve to 3500 PSIG. During the fill, the free floating piston bottoms out in the accumulator cylinder. The flexible bellows reservoir is

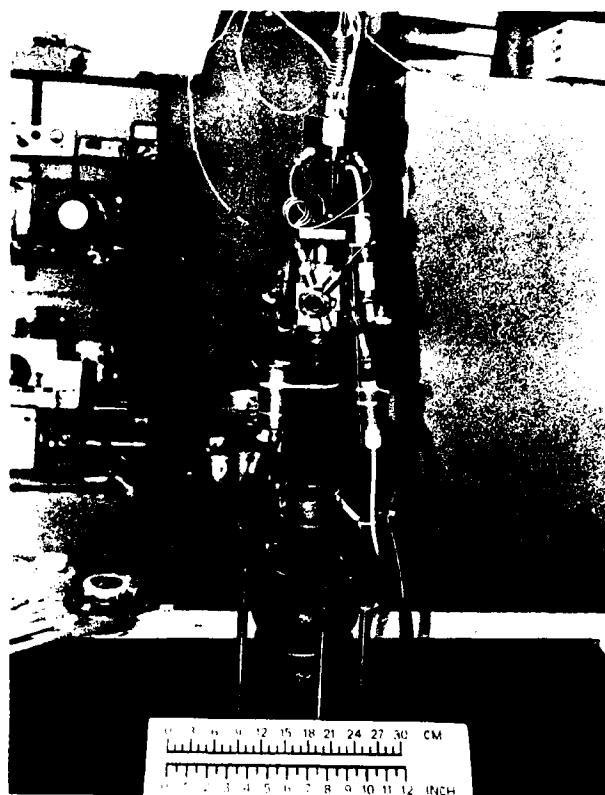


Fig. 40a. Nitrogen System

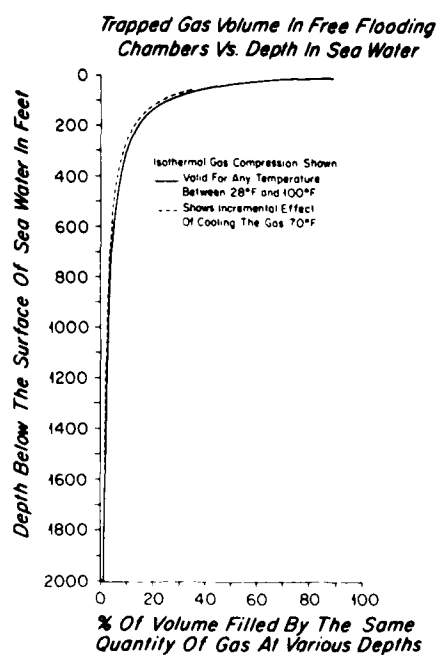


Fig. 41a. Isothermal Gas Compression VS. Depth in Feet Below the Surface

backfilled with any fluid that will not freeze or congeal at 34 degrees F. In this case, a water base hydraulic fluid that was doped with ethylene glycol to reduce its freeze point to below 32 degrees F was selected.

The bladder volume exceeds the internal volume of the accumulator, assuring sufficient pressure compensation fluid to fill the fluid side of the accumulator as the 3500 PSIG nitrogen charge compresses during the descent through the water column.

With the system initially charged to 3500 PSIG, the compensation system will pressure balance the motor housing until the outside ambient sea water pressure equals the internal nitrogen charge pressure remaining in the accumulator. Continued descent applies increasing pressures on the fluid filled bladder which in turn applies an equal force against the floating piston. As the piston moves, it compresses the nitrogen to a pressure essentially equal to the outside ambient sea water pressure.

The compressing action will bootstrap itself until the pressure depth has compressed the nitrogen to a point where the volume has decreased sufficiently that it allows the piston to bottom out at the stop on the nitrogen side. Figure 40 illustrates the first nitrogen compensation system used for the initial testing of the concept.

Referring to Figure 41 - an isothermal gas compression curve VS trapped gas volume change due to depth variations - approximately 90 percent of the volume change takes place in the first 300 feet of descent. This represents a pressure change of 130 pounds per square inch.

The accumulator pre-charge is 3500 PSI, which represents a pressure

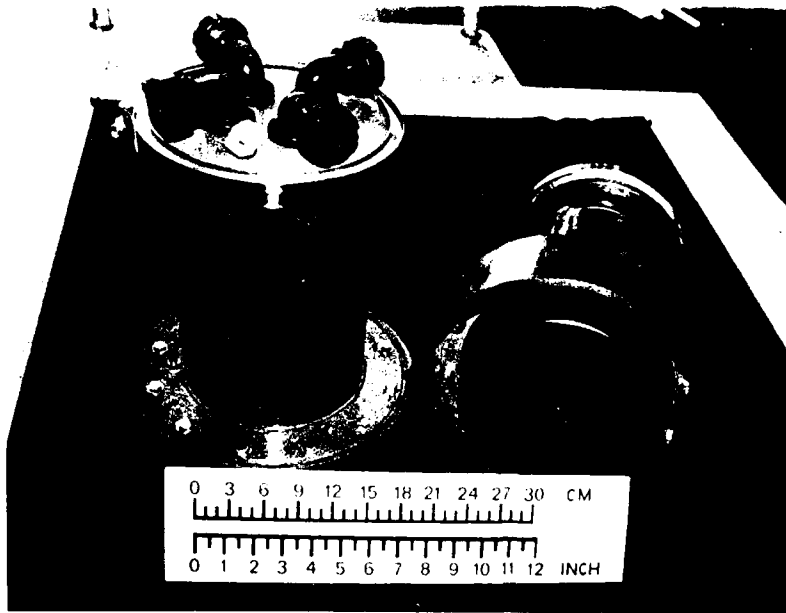


Fig. 42a. Relay
Control Pod
Assembly

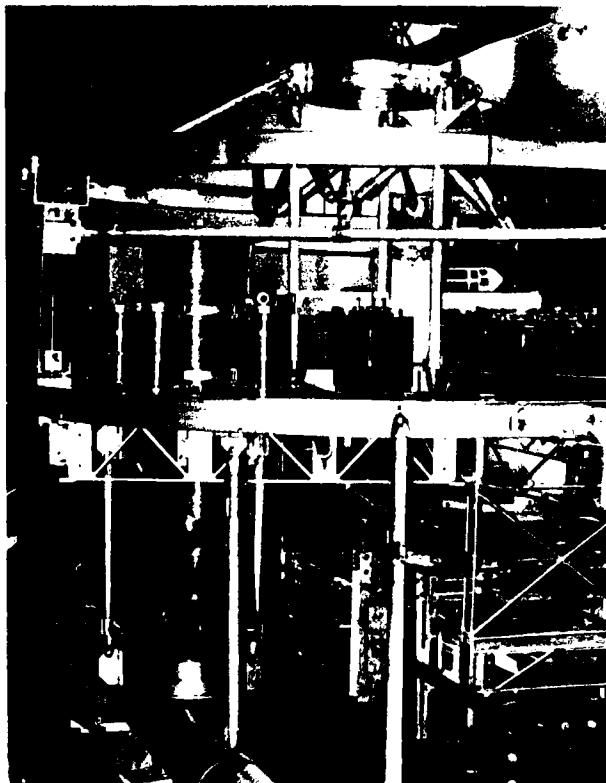


Fig. 43a. Typical Control Pod Mounting Configuration

depth of 8000 feet. Referring to the curve, note the isothermal gas compression is essentially a straight line from 1200 feet down, with the remaining percentage of volume change being minimal. Based on this, the accumulator free floating piston must only bootstrap a very small volume of gas as it descends to its operational depth of 5000 meters.

5.0 Relay Control Pods

Figure 42 illustrates a typical relay control pod. There are eight pods mounted around the periphery of the hydraulic system canister as shown in Figure 43. All pods are mirror images of each other, are constructed of welded and cemented PVC material, and are pressure compensated by the TU-79 molded bladder (shown at the base of the pod cross-section in Figure 44). A vee-band clamp and O-ring seal in the cover plate allows rapid access to the internal components which can be removed for maintenance without draining the MARCOL 52 compensation fluid.

Figure 45 illustrates the internal mechanical layout of a typical relay control pod. Each pod contains provisions for six 12 volt pulse-type mechanical latching/unlatching relays. The contact rating on the smaller relays are 15 amperes while the single contact of the battery pack control relay is 20 amperes each, providing a double contact capability of 40 amperes. The relay is activated by the use of a 24 volt pulse, which assures the relay will pull in and not be adversely affected by the damping action of the compensation oil.

The 90 degree fittings shown on the end cap are typical of all penetrators that are part of an oil-filled system on the HEBBLE Sea Duct. They are

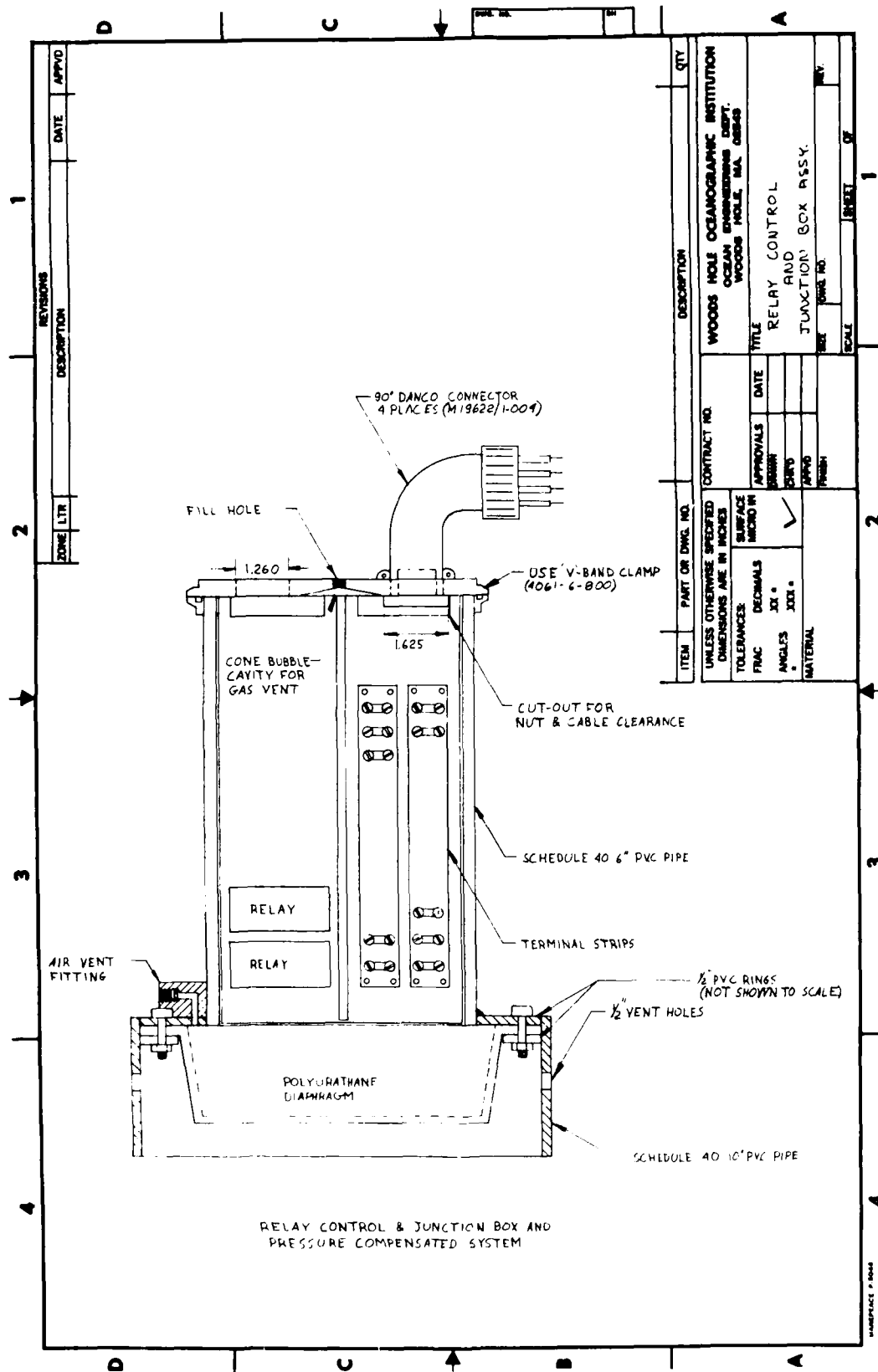


Fig. 44a. Relay Pod Cross Sectional Sketch.

Danco fittings constructed with an external plastic shell and a removable internal rubber stopper. The control wires are inserted through holes in the conical stopper. By tightening the gland nut, the stopper squeezes around the wires forming a water and/or oil tight seal. The Danco plastic penetrator feed-thru fittings are manufactured by the PENN-EL Electric Company.

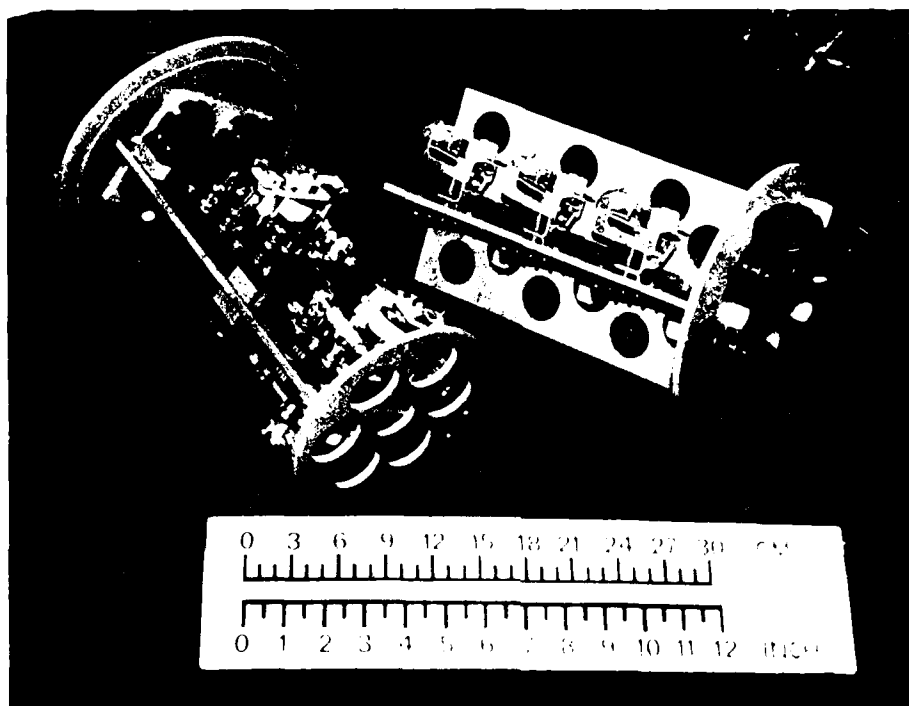


Fig. 45a. Internal Mechanical Layout of Relay Pod

6.0 Hydraulic System

The Sea Duct hydraulic system provides the force that performs all mechanical movements of the recirculating flume ancillary systems. Its design follows conventional hydraulic system standards and for the most part, off the shelf components. It uses MIL H-5606 hydraulic fluid, a red mineral oil that has an excellent history in aircraft, surface and subsurface systems.

The hydraulic package provides the following motions: rotation of the carousel and flume assembly, traverse and positioning of the X-Y-Z carriage,

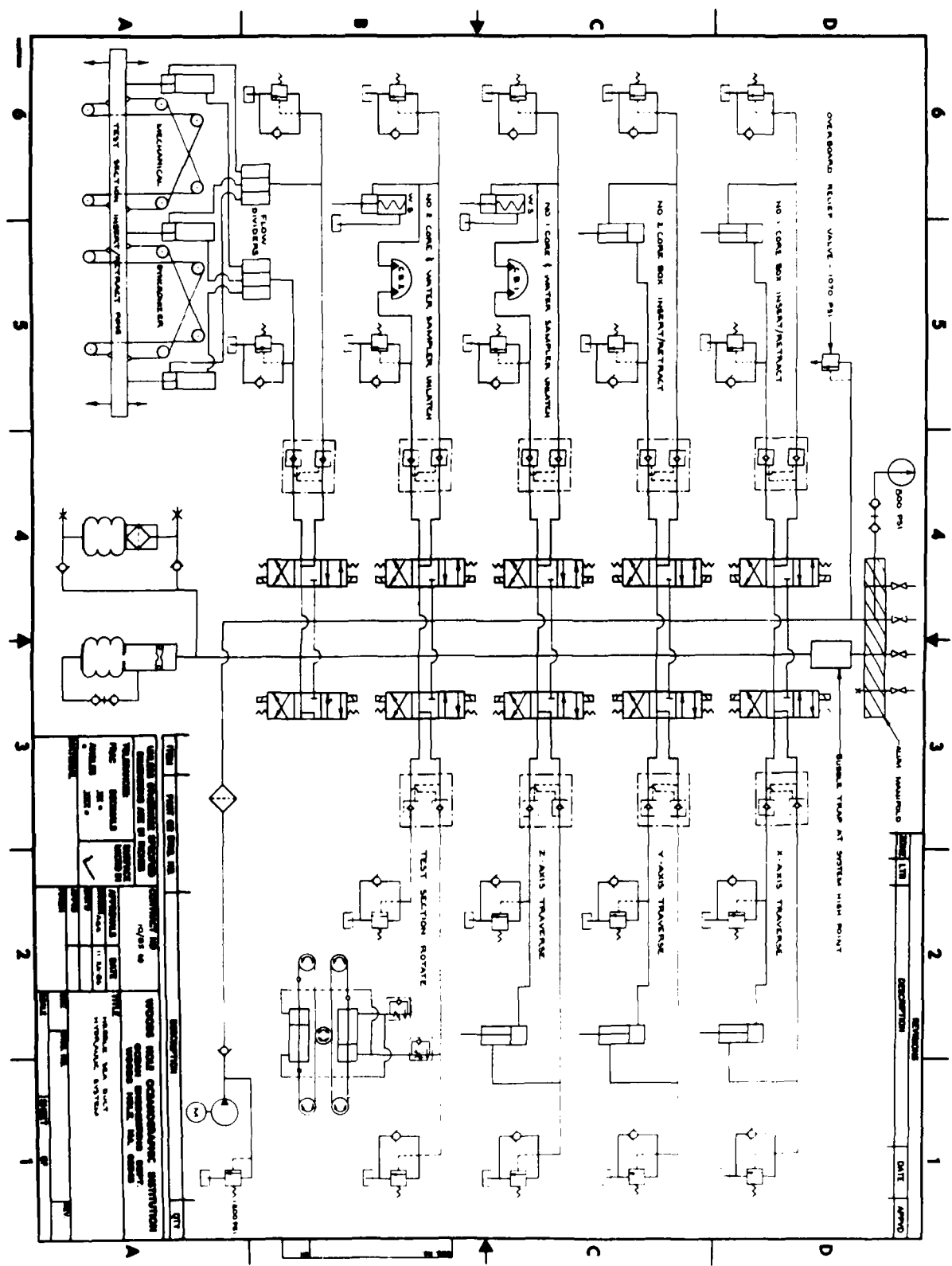


Fig. 46a. Hydraulic System Schematic.

flume insertion in and retraction from the sea bed sediment, insertion and withdrawal of two sediment core samplers, and activation of the three water samplers. The system is controlled by a microprocessor sequencer assembly with magnetic switch and LED feedback position sensors.

6.1 Hydraulic Pump and Motor Assembly

The hydraulic pump has internal pressure balancing of the shafts and gears which substantially reduces bearing side loads and housing wear while improving pumping efficiency. It is a conventional Model OP-3003 gear pump manufactured by Dowty Hydraulic Ltd.. The theoretical displacement of the pumps is .08 cubic inches per revolution, with a delivery rate of .3 U.S. gallons per minute at 1500 rpm. It is capable of generating a continuous pressure of 3000 PSIG at 4000 rpm. In actual system operation it is driven at approximately 1400 rpm with an output of 825 PSIG. By design, it is a lightly loaded pump and should have an excellent longevity.

The pump is direct coupled to an Electro-Craft Model 702 motor with an 'A' type winding for use on 24 volt D.C. It is a permanent magnet device with an output torque of 275 ounce inches at 1400 rpm. The hydraulic pump requires 122 ounce inches of torque to provide 825 PSIG at slightly less than 0.3 gpm, providing a reasonable safety factor of better than 2:1.

The motor is pressure compensated, using the nitrogen bootstrap compensation system discussed in Section 4.0.

6.2 Hydraulic System Schematic

Figure 46 is the circuit diagram for the Sea Duct hydraulic package. All directional control valves are off the shelf spool type with 12 volt solenoid coils, and are manufactured by the Double A Company, a division of

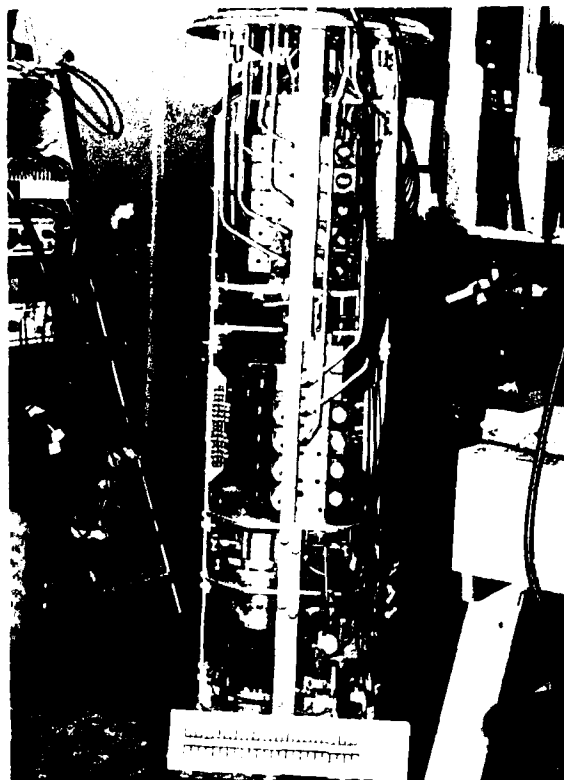


Fig. 47a. Hydraulic System Component Package

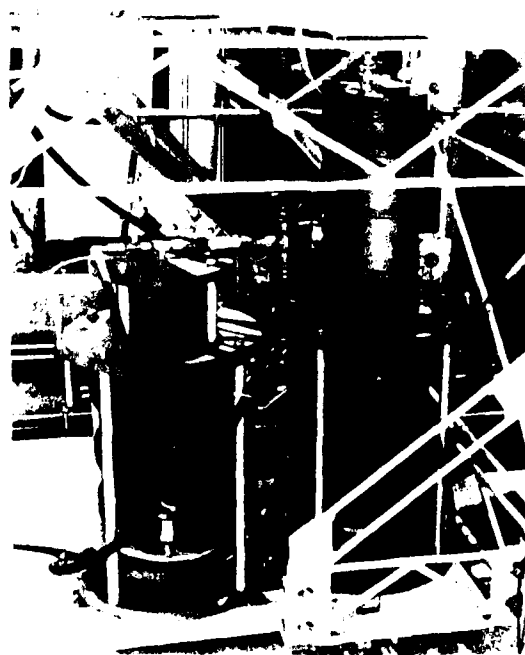


Fig. 48a. Hydraulic System Compensation and Oil Storage Reservoir

Brown and Sharp. The vendor's stock number is #QF3-FF-10A1-DC12. The spools are ground and sized for maximum efficiency (minimum leakage loss) at 34 degrees F ambient operational temperatures.

The pilot-operated check valves located adjacent to the directional valves reduce cylinder creepage over extended periods of down time. The counter balance valves found on both the rod and piston side of each hydraulic actuator provide free flow of fluid from the reservoir, effectively pressure compensating the system during descent through the water column. As the Sea Duct returns to the surface, the relief valve section will vent any trapped pressure that is in excess of 1200 PSIG.

The two sediment sample unlatch actuators provide a 90 degree rotary motion to release spring loaded jaws that close and trap the sample within the core box. They are manufactured by the PHD Company in Fort Wayne, Indiana, and have been modified to allow oil compensation of the internal rack and pinion assembly.

Figure 47 illustrates the mechanical layout of the hydraulic package. Liberal use of drilled and ported manifold blocks substantially reduce the use of interconnecting tube and fittings. The complete package is encased in an oil-filled fiberglass tube. Its construction and pressure compensation system is identical and interchangeable with the lead acid battery canisters.

6.3 Pressure Compensation and Hydraulic Reservoir Assembly

Internal pressure compensation of the system is provided by two free floating piston accumulators that separate the hydraulic fluid from direct contact with the water base hydraulic fluid contained in the flexible accor-

dion bellows. Figure 48 illustrates the dual piston accumulator on the right. As system modifications were made to include other items of ancillary hydraulics, it became obvious that the bulk modulus of the MIL-H-5606 hydraulic fluid (approximately 1/2% reduction in volume per 1000 PSI), plus the additional fluid required for simultaneous operation, was beginning to reach the system volume limitations at a 15,000 foot depth.

To alleviate the marginal condition, a second accumulator was placed in the system. Its construction differed considerably from the piston unit; it retained the neoprene elastomer bellows, but did not make use of a floating fluid separation piston. As noted in Figure 46, the system hydraulic fluid completely fills the compensation bladder. Check valves and internal filters continuously direct the fluid through the filter element as the system withdraws fluid for cylinder extension. Return flow from retracting cylinders expands the bellows reservoir storing the fluid for the next cycle. Being in direct contact with the sea water, the bellows maintains system compensation at any depth. It is mounted adjacent to, and piped in parallel with, the free piston accumulator as shown in Figure 48.

6.4 Test Section Rotary Carousel Drive

The rotary drive mechanism used to rotate and position the test section to a pre-selected heading is powered by hydraulics. Referring to the system schematic, Figure 46, the rotary motion is generated through the linear travel of two double rod cylinders operating in series.

The pistons of each double rod cylinder operate in a push-pull mode which doubles the available force; the average force generated by the two pistons being 5000 lbs. The linear travel is converted to a rotary motion

through the use of double strand roller chains and mating double tooth sprockets. The rotary torque applied to the carousel drive shaft is 7400 inch pounds. A universal joint is positioned between the drive sprocket and the carousel to correct any misalignment that could result from slight twisting of the frame.

Two hydraulic flow control valves are used to regulate the rotational speed of the carousel. They provide free flow in the pressurization mode, and have an adjustable restriction or orifice in the return flow side. They are standard items of hydraulic hardware manufactured by the Pneu-Trol Co.

6.5 Test Section Insert/Retract System

The insertion and retraction mechanism for the Sea Duct test section consists of three hydraulic cylinder assemblies, equally spaced around the eight foot diameter trolley ring. Figure 14 illustrates a typical trolley and hydraulic cylinder mechanism, with the self aligning slip pad and universal joint secured to the base of the piston rod. A single cylinder can exert 5800 lbs. of insertion force, and when reversed has the capability of providing a withdrawal capacity of 5400 lbs.

The synchronization of three hydraulic cylinders is an interesting design problem. In the case of the Sea Duct flume, the test section must be inserted into the sediment as evenly and level as possible. Uneven insertion could allow either a build-up or depression to be formed at the interface of the test section duct transition piece, disturbing the internal fluid flow as it passes over the obstruction. The lead filled flexible plastic flaps illustrated in Figure 20 assist in smoothing any minor obstruction, but major sediment disturbance is not acceptable.

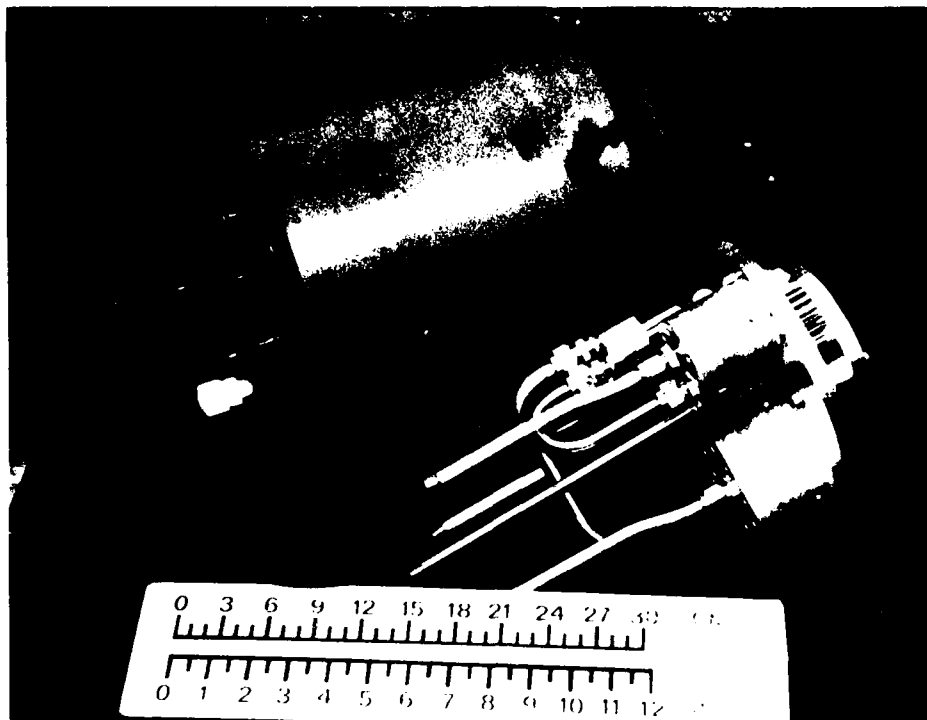


Fig. 49a. Flow Divider Pump Assembly

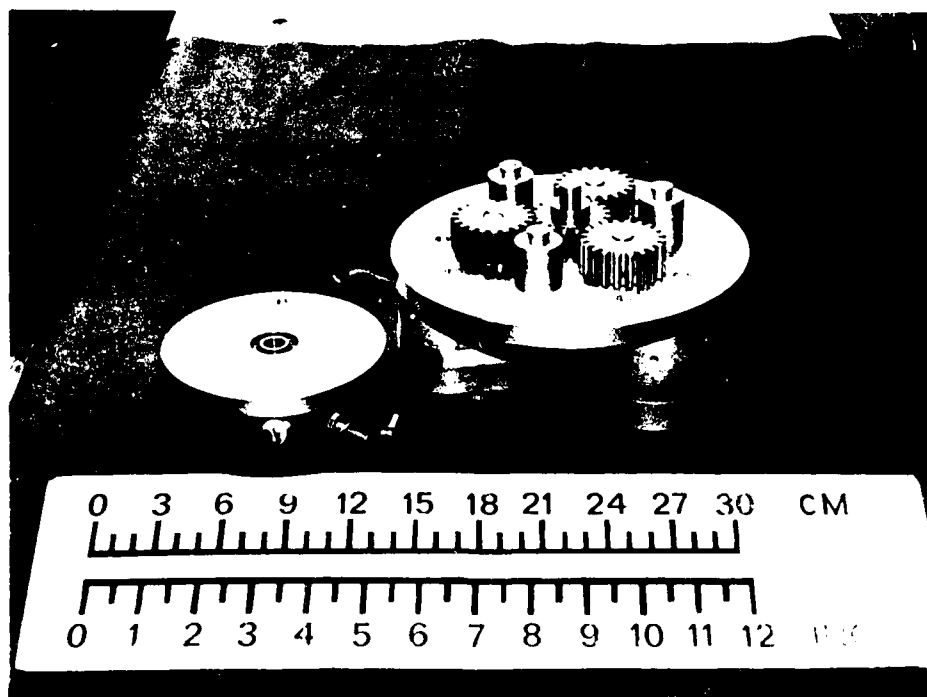


Fig. 50a. Flow Divider Gear Train

To assure synchronization, a three stage flow divider consisting of three hydraulic motors having one common inlet port was designed and built. Figure 49 illustrates the flow divider motors and their outer compensation housing. The motors are geared together to assure a common rotation; no one motor can overrun or lag behind the others. Figure 50 provides a clear view of the gear train assemble. The common inlet applies the pressurized hydraulic fluid to the individual pumps. Being positive displacement devices, they pass an equal volume of fluid which in turn is directed to individual insert/retract cylinders. Similar to the other components in the system, the flow divider is a pressure balanced device, and is mounted in an oil-filled canister and bladder assembly.

Flow division through the pumps was only marginally acceptable. Attempting to equally divide 0.3 GPM into three equal volumes requires extremely accurate gears, essentially no internal leakage, and a complete absence of entrapped air. To guarantee precise and equal extension and retraction, a mechanical cable system was installed. Figure 51 provides a self-explanatory sketch of the device.

7.0 Instrument Pressure Housings

The pressure housings that contain the microprocessor, emergency battery, and the emergency release system valve mechanisms, are machined from 7075-T6 aluminum alloy. The housings are twelve inch O.D. with a one inch wall. The end caps are twelve inch O.D. with a two and one half inch thickness. To reduce corrosion and enhance abrasion resistance, they are processed with a $.00015" \pm .0005"$ thickness of hard coat, an electro-chemical anodizing treatment that converts the surface into a hard aluminum oxide material.

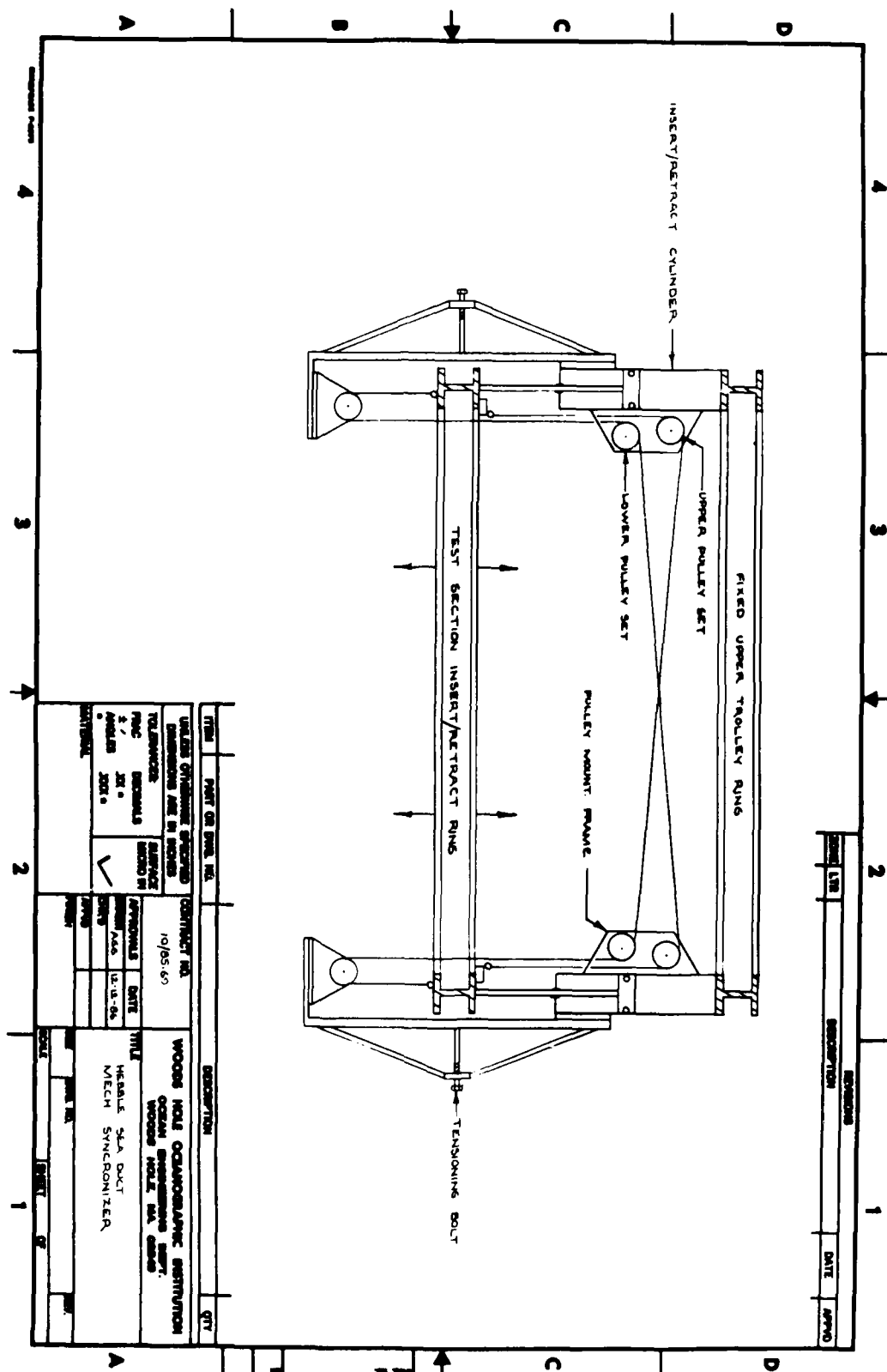


Fig. 51a. Mechanical Cable Synchronizer Assembly.

7.1 Microprocessor Sequencer Housing

The end cap for the assembly required a unique design approach; approximately 100 pressure resistant wire penetrations were required. If the standard multi-pin bulkhead penetrator was used, the end cap would be so riddled with large diameter holes that it would not have the strength to resist the pressure at a 5000 meter depth.

To circumvent this problem, small glass-to-metal center pin headers having a 1/4-28 straight thread and sealed with an O-ring were used. They are solder-type connectors and can provide a high density end cap package as illustrated in Figure 52. The PVC ring provides sufficient area on its outside diameter to allow for spot facing, and tapped holes for the conventional penetrators.

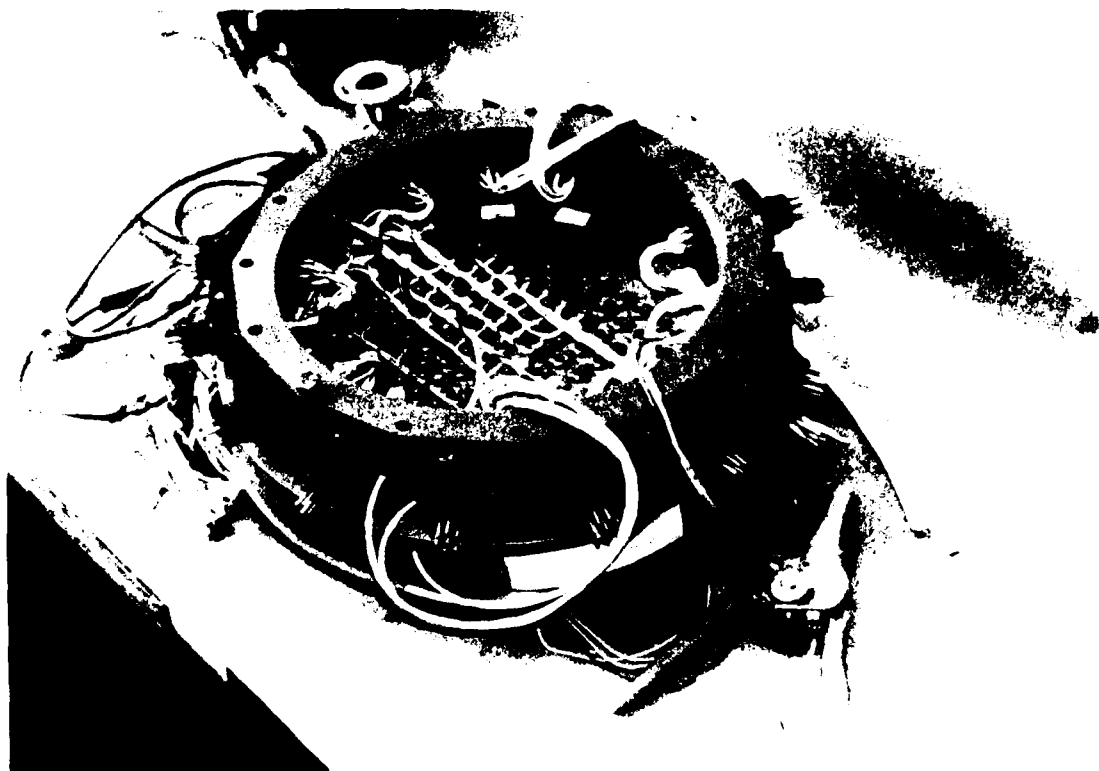


Figure 52a

The PVC ring also forms a part of the oil-filled pressure compensation housing that protects the exposed header pins from contact with sea water. An elastomer diaphragm and cover plate complete the assembly, as shown in Figure 53.



Figure 53a

The design stress calculations for all the housings were based on a service depth in excess of 23,000 feet, or 7000 meters. The actual depth at the HEBBLE site is 5000 meters; this provides a substantial margin of safety.

Two completed shells, one emergency battery, and one emergency release housing, were assembled and prepared for an external hydrostatic pressure test of 10,000 PSI for a 15 minute period. At 9600 PSI, housing #1 imploded as a result of an end cap failure. Figure 54 illustrates the disc punch-through of the failed assembly.

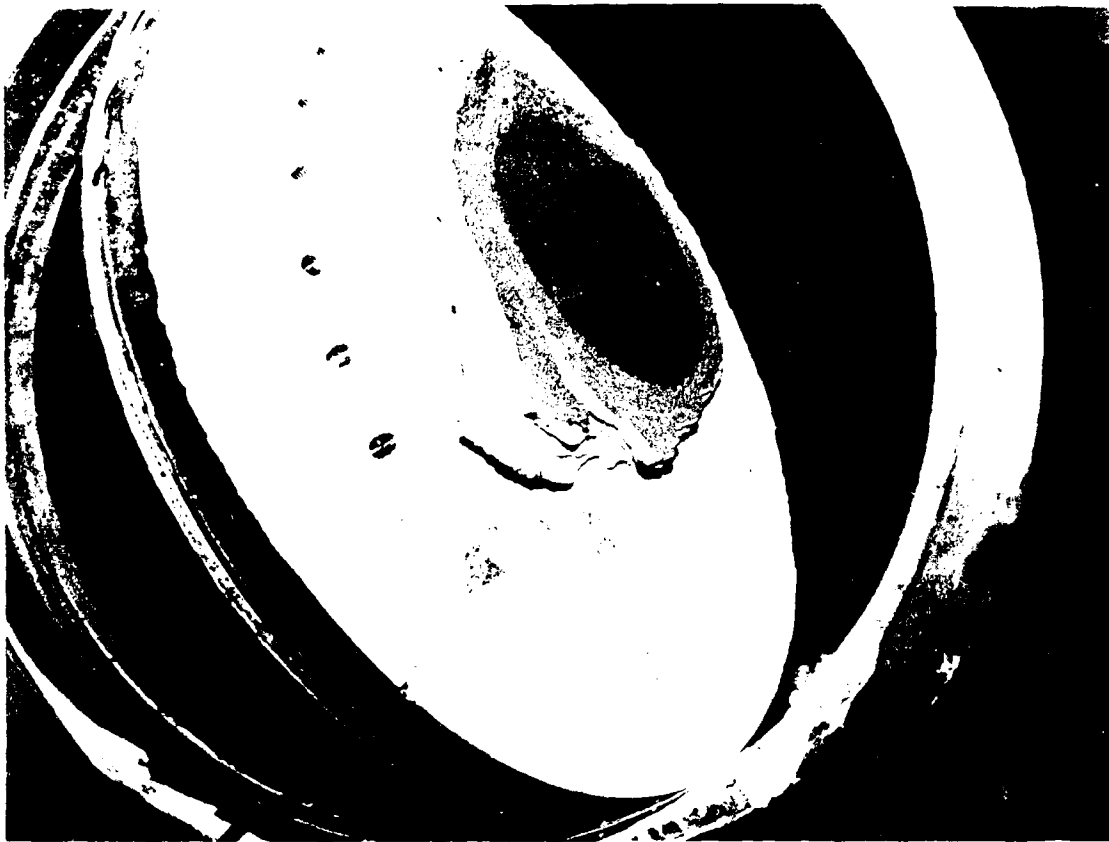


Fig. 54a. Hydrostatic Pressure Test Failure of Housing #1 End Cap

The second housing was prepared for testing. As the external pressure was slowly increased, end cap failure again occurred - this time at 7800 PSI. Figure 55 shows the shattered end cap of pressure housing #2. At this point, all fabrication of pressure housings was halted. The design was re-evaluated and found to be satisfactory and in accordance with standard design practice for externally pressurized housings and end caps.

Arrangements were made to have the Arnold Greene Testing Laboratories, Inc. perform a complete analysis on the material used in fabrication. The contract, P.O. #19478 and Arnold Greene Job #37357, included the following format for investigation.

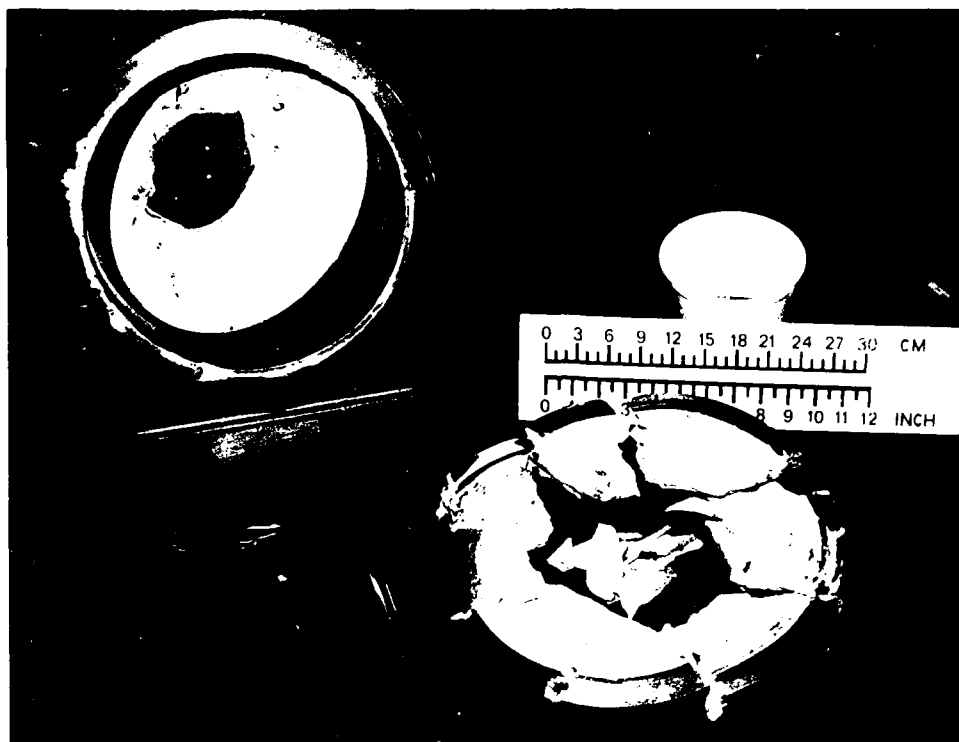


Fig. 55a. Hydrostatic Pressure Test Failure of Housing #2 End Cap

7.2 Investigative Failure Procedures for Hydrostatic Test Implosions

1. Sample Identification
2. Background of Material
3. Background of Tests Resulting in Failure
4. Radiographic Examination
5. Chemical Analysis Including Hydrogen Content
6. Physical Tests: Tensile, Hardness
7. Metallographic Examination, Including Microstructure Scrutiny
8. Determination of Hardcoat Thickness and Condition
9. Microscopic Examination
10. Analytical Discussion
11. Conclusion and Final Report

Two (2) instrument cases with failed end caps were submitted for metallurgical evaluation; related drawings and pressure test reports were also included. For the purpose of comparison with the failed samples #1 and #2, an intact end cap was submitted as sample #3.

The preliminary examination showed both failed end caps displayed a brittle, layering cleavage-type fracture apparently initiating in general from the top circumferential region toward the cap center within a circular radius of approximately two inches from its center.

Serious scuffing and abrasion is shown on the circumferential edges of the case, at the positions of cap/case mating. The hard coat surfaces on the case edges have been scuffed away.

Visual and stereomicroscopic examination of the end cap fracture sections in the immediate area of visual "river bed" markings confirm that the direction of cracking fracture propagation was from the cap top near the center position, outward. An X-ray examination was performed on the intact sections of the end cap sample and found to be free of porosity discontinuities.

A hydrogen "vacuum" fusion determination was performed on the fragmented sections of end cap #1. The hydrogen content, which was 4.7 parts per million and not considered as excessively high, is probably not a factor in the end cap failure. The samples tested conform to 7075 aluminum alloy chemical specification limits. All samples tested closely track each other.

Physical testing of samples of the end cap material provided the following data:

Hardness Survey

Sample #1 cap - 143 brinell (500 kg load)
Sample #2 cap - 158 brinell (500 kg load)

Tensile Test

Sample #1 - using a .505" diam. plug machined from the center of a failed end cap.
Sample #3 - using a .505" diam. plug machined from the center of the intact end cap.

Sample	Tensile	Field	Elongation
#1 cap	80,900 PSI	69,690 PSI	9.7%
#3 cap	81,400 PSI	68,090 PSI	9.7%
Nominal	82,000 PSI	72,000 PSI	11.0%

A metallographic examination included the determination of hard coat thickness and condition.

Sample	Thickness	Hardness
#1 end cap	0.00311"	28 HRC
#2 end cap	0.00305"	31 HRC

Specification Requirement: $0.00015" \pm .0005$

The examination revealed the hard coat thickness was not within drawing specifications. Microscopic examination of the anodized layer of specimens #1 and #2 reveals multiple cracking and some voids.

7.3 Discussion of Data Obtained

Based on the Arnold Greene Laboratories Test and Evaluation Report, the following information was submitted:

- All samples of end caps do conform to chemical specifications for 7075 aluminum alloy
- Hydrogen embrittlement is not considered to be a factor in the failure
- The anodize "hard-coat" on all end caps was excessively thick as related to the specification. It also exhibits multiple micro cracks.

The thicker anodized surface involving micro crack presence tends to offer notch stress concentration points which may contribute crack origin positions. Although there are no hardness specification covered by the hard-coat requirements, the actual hardness rating of the samples appears to be relatively low.

Some distinct indications of eutectic melting and fragmented grain structure shows in microstructure examination of the tearing fracture pieces of sample caps #1 and #2. This condition is caused by slight overheating - probably in the solution heat treatment - and can impart brittleness of the metal grain boundary in these areas. There is also clear indication, especially in #1 cap sample, of serious overaging heat treatment in some regions of the end cap resulting in strength deterioration.

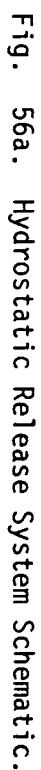
7.4 Failure Analysis Conclusion

The major failure cause of end cap implosion is the result of slight overheat in the solution heat treatment, leaving areas of grain eutectic melting embrittlement. This was confirmed by microstructure examination.

In view of the design drawing, stress calculation review, and the Arnold Greene Technical Evaluation of the end cap material, no drawing modification was required. New housings and end caps were fabricated and successfully passed all external hydrostatic pressure testing. Vendors for raw material were required to certify the material was 7075-T6, rolled plate stock, and was not plasma cut or overheated during cutting.

8.0 Hydrostatic Release System

The three release mechanisms used to separate the ballast weight foot pads, lead acid battery packs, and the emergency grapple floats are operated by using the energy generated by hydrostatic pressure. Figure 56 illustrates the system schematic. Each release assembly has been designed to be a mirror image of its counterpart. Any one component can be used as an interchangeable part in any of the three systems.



In preparation for use, the piston rods are pushed into the fully retracted position as illustrated on the system sketch. The oil-filled bladder side, inter-connecting tube runs, and the back of the pistons are burped of as much trapped air as possible. It is not mandatory to remove all air from this portion of the system. As long as any remaining voids are less than the volume of the individual oil-filled bladders, the system will operate satisfactorily.

The opposite side, or rod end of the pistons are back filled with oil directly up to the motor driven valve assembly. It is best to oil-fill each system by opening the individual control valves, disconnecting the tube run at the manifold block and applying pressurized oil through point 'A'. It is mandatory to remove all air bubbles from the valve, tube runs, and especially the larger volume contained in the individual piston/cylinder assemblies. Any entrapped air on this side will compress as the system descends through the water column, allowing the piston rod to extend, which could result in an inadvertent release.

After filling, the system control valve is electrically closed and the tube run is connected to the manifold block at point 'A'. The 150 cubic inch hard volume must not be allowed to accumulate oil at any time during the filling cycle.

Control of an individual system release valve is directed by the micro-processor. The three valves are contained in a dedicated pressure housing shown as the horizontal cylinder in Figure 57. The 150 cubic inch hard volume is the vertically mounted chamber with a hydrostatic release cylinder located at its left. A typical oil-filled bladder is shown midway between the release

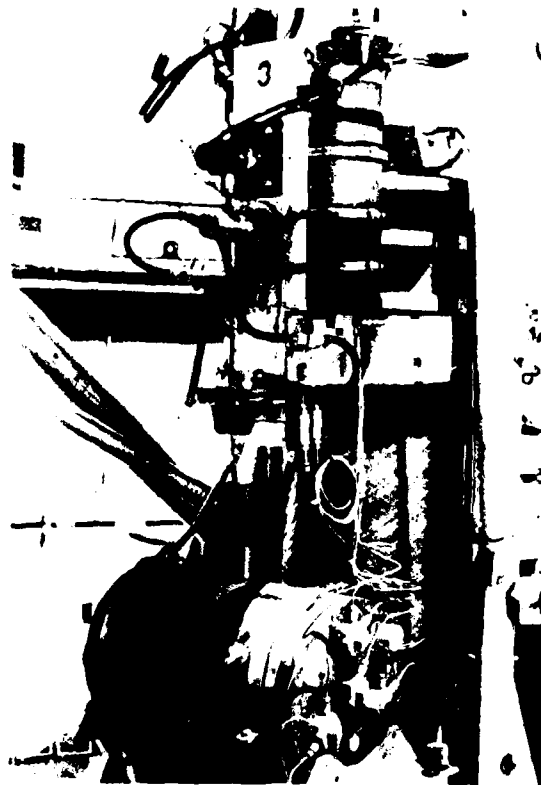


Fig. 57a. Hydrostatic Release Mechanism Pressure Housing

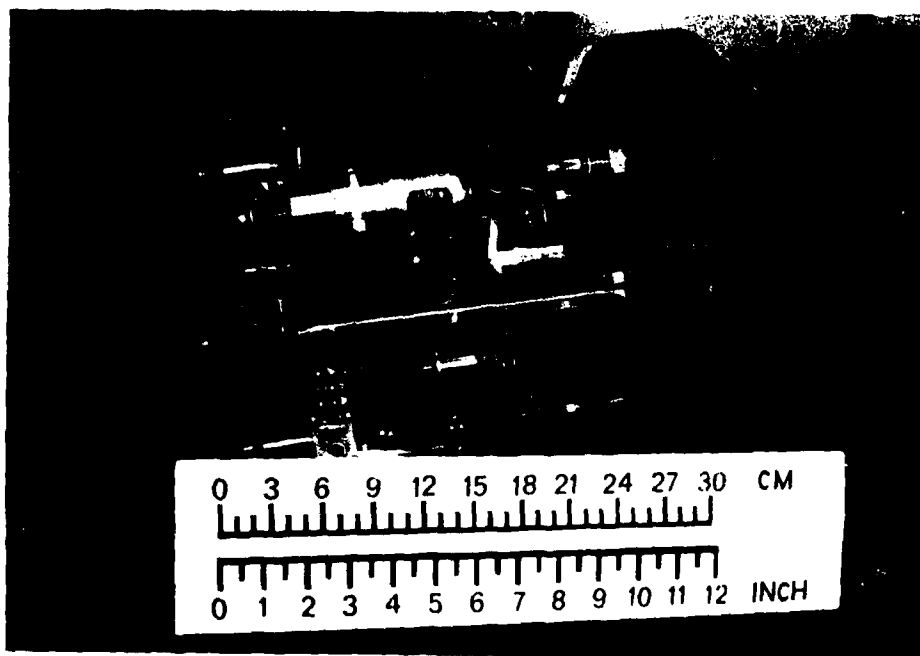


Fig. 58a. Hydrostatic Release Motor Driven Valve Assembly

and horizontal valve housing. Directly to the right of the bladder are the two relief check valves and the oil-filled loop that prevents sea water from direct contact with the relief shuttle and spring.

The three valve mechanisms are motor driven through a gear train and slip-type clutch assembly. Figure 58 is an internal view of the gear drive train, valves and the microswitch that opens the electrical circuit when the valve has been driven to the full open position. In the closure mode, the motor drives the valve closed until a friction clutch slips. The motor is a 12 VDC, 300 RPM device, developing 18-inch ounces of torque. It is actually powered by 24 VDC to assure the valve will open under unfavorable conditions. It has a 12 second open or close duty cycle and is not adversely affected by the over voltage. Figure 59 depicts the electrical schematic of the valve system. As originally assembled and wired, there was a sporadic interaction between motors. The insertion of blocking diodes in the circuit eliminated the difficulty.

Referring to Figure 60 - A Cross Section of the Hydrostatic Release Assembly - the male cone shown at the left is secured to the device to be released. On assembly, a 1/4 inch diameter fibreglass shear pin is inserted through mating holes in the male and female cones. On actuation, or opening of the system valve, hydrostatic pressure pushes against the piston, forcing fluid into the 150 cubic inch evacuated hard volume chamber. The piston rod continues to extend until it shears the fibreglass pin, allowing the device to drop away.

The force required to shear the fibreglass pin was determined through the use of a test fixture identical to the release cones used on the HEBBLE Sea Duct.

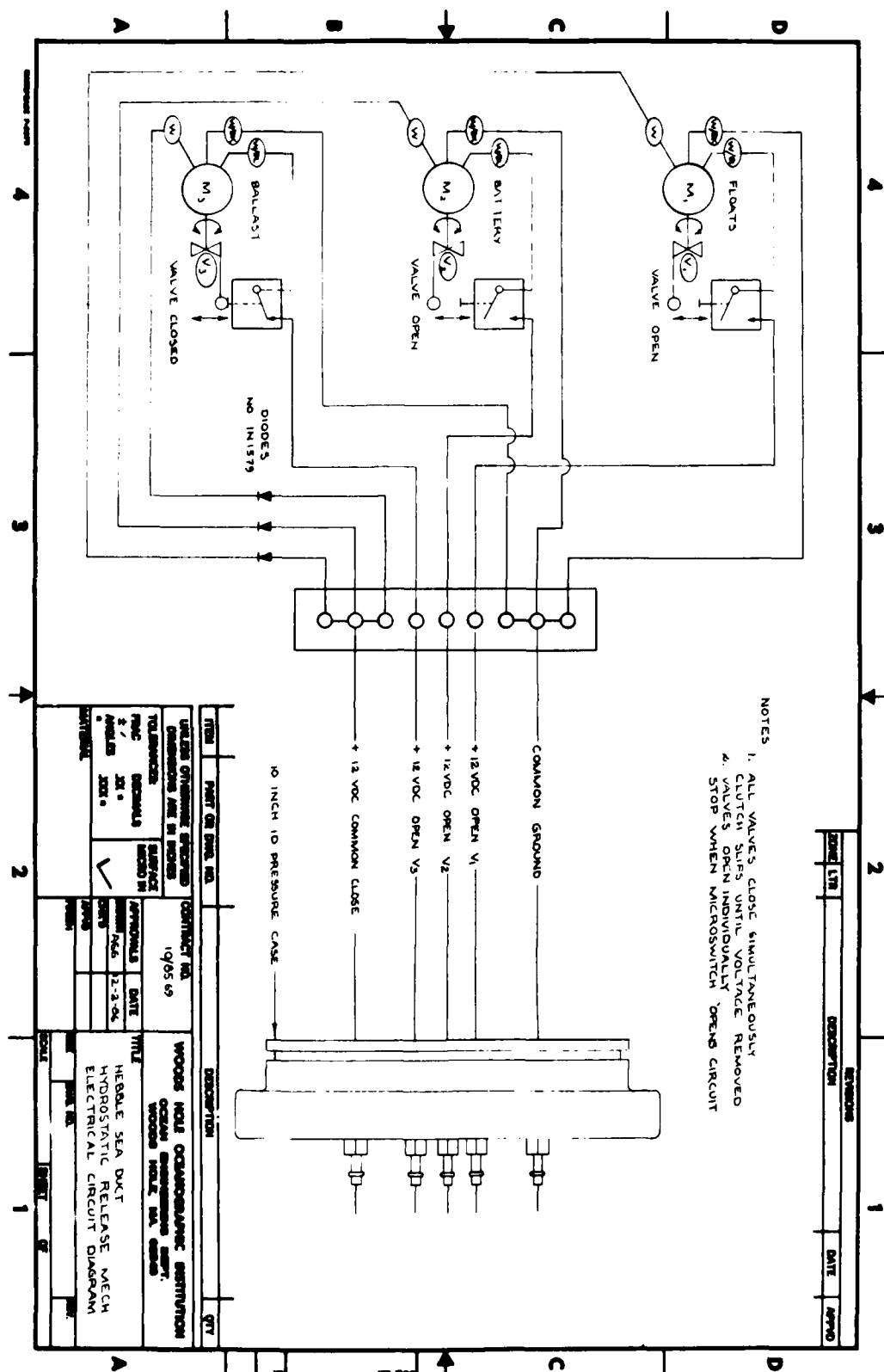


Fig. 59a. Hydrostatic Release Valve/Motor Electrical Schematic.

8.1 Machined Male/Female ST/SL Cone Shear Data

Referring to Figure 61 - two separate sets of fibreglass pin, shear tests were performed. On the left, close fitting machined cones were used. Four shear tests were conducted using a Baldwin Model C8 tension/compression materials testing machine. A test fixture and fibreglass shear pin similar to the cross-section of Figure 60 was installed on the machine test bed.

Separate tests were performed at increasing load rates of approximately 50, 500 and two 1000 lbs/second. Tests indicate that a 'notch', or needle flick, followed by a definite slowdown of the speed of load application, was observed between 800 and 980 lbs. of applied load. Continued application of the applied force resulted in total shear pin failure at loads between 1520 and 1700 lbs.

8.2 Cast Iron Male Cone/Machined Female Cone Shear Data

The second set of tests were conducted in order to determine the effect loose fitting, rough cast iron cones would have on the shear loads. There have been several reported shear pin failures resulting from 'in air' shock loads that were impressed on the ballast weight feet as the crane operator either snapped the lift or braked abruptly.

Referring to Figure 61, the cone configuration at the right side represents the dimensions of a loose fitting typical cast iron male cone; the female dimensions remain as in previous tests.

Four tests were performed using increasing load rates of 50, 500, and two 1000 lbs/second. There was only one indication of a 'notch', or partial shearing of the fibreglass rod, which could have been a result of the mating parts being in direct contact on one side. As would be expected, the 'notch'

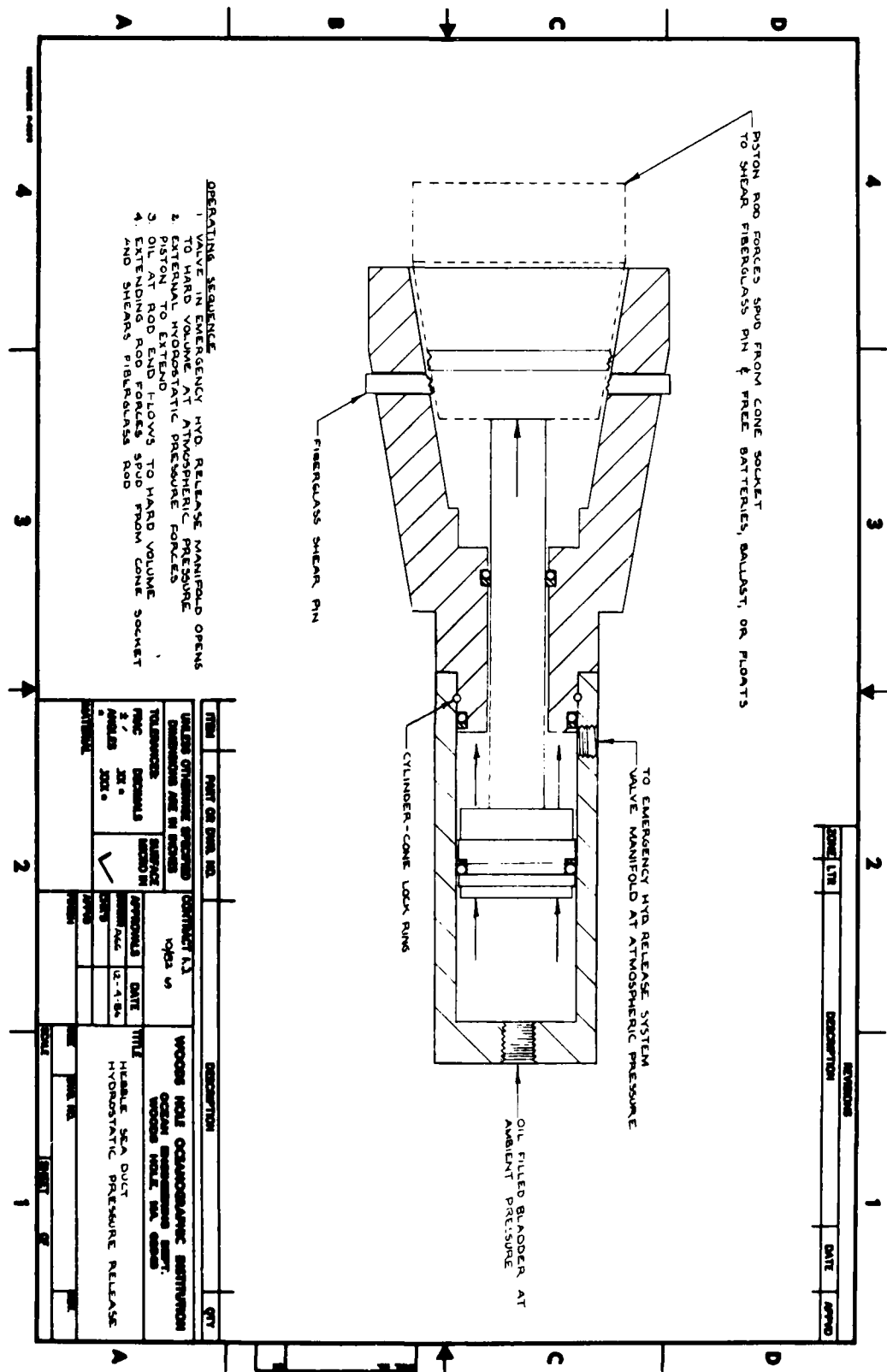


Fig. 60a. Cross Section Mechanical Shear Pin/Cone Assembly.

final load failure was the high reading, or 985 lbs. at pin shear, with the remaining test spread falling between it and the low point of 965 pounds.

Based on the low loads required to shear the fibreglass pin when used with sloppy fitting cones, it is not recommended for any release that is critical to system success. It is strongly urged that under no circumstances should deck personnel be permitted to be close to any airborne system using loose fit cones.

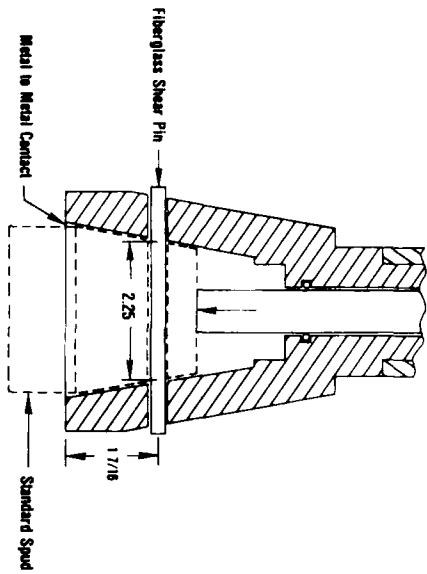
8.3 Hydrostatic System and Shallow Water Operation

As shown by the pressures required to shear fibreglass pins in close fitting cones, shallow water operation requires the use of some type of ancillary support system.

Referring to the piston that applies the pressure to shear the fibreglass pin, it has a surface area of 1.76 square inches. To generate a shear force of at least 1000 lbs., it would require a pressure depth of 570 PSI, or roughly 1317 feet. If the Sea Duct were to be used in shallow depth deployment, a means of applying an elevated pressure must be artificially produced. Figure 62 is a system schematic that could provide the required pressure. Note the oil-filled bladders have been removed and the pressurizing system plumbed directly into the piston side of the release assembly. All oil back fill precautions remain as previously discussed.

9.0 Specimen Sampling and Stereo Camera System

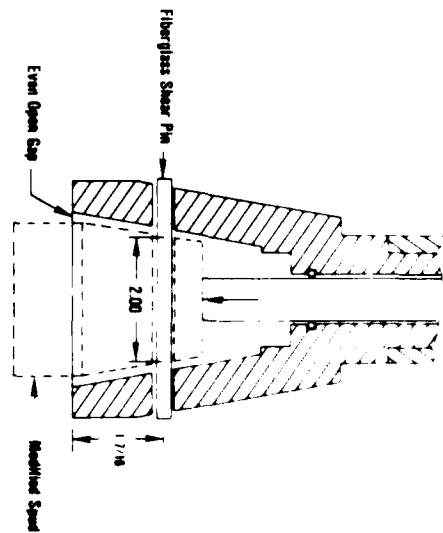
The sampling systems on the HEBBLE Sea Duct consist of sediment core boxes, water samplers, and a stereo camera system.



Machined Mating Cones

Assume Metal to Metal contact at 1 7/16" dimension
All Shear pins cut from same 1/4" fibre glass rod

- Test 1** Assume approximately 50 lb increase per sec. loading 0-2400 lb range on Baldwin
- A- Initial 'notch' noted on scale at 800 lbs.
 - B- Gage reading slowly decreased at that point
 - C- Increased load to above 50 lbs./sec.
 - D- Total shear failure occurred at 1520 lbs.
- Test 2** Assume approximately 500 lb. increase per sec loading
- A- Initial 'notch' 960 lbs. no rate increase req.
 - B- Continued same rate of loading
 - C- Total shear failure occurred at 1840 lbs.
- Test 3** Assume approximately 1000 lb. increase per sec. loading 0-2400 lb. range
- A- Initial 'notch' noted at 880 lbs. no rate increase req.
 - B- Continued at same rate of loading
 - C- Total shear failure occurred at 1760 lbs.
- Test 4** Assume approximately 1000 lbs. per sec. loading
- A- Initial 'notch' 980 lb. no rate increase req.
 - B- Continued same rate of loading
 - C- Total shear failure occurred at 1700 lbs.



Male Cone Modified to Conform to Casting Size

Assume even open gap on both sides at 1 7/16" dimension
All shear pins cut from same 1/4" fibre glass rod

- Test 1** Assume approximately 50 lb increase per sec loading 0-2400 lb range on Baldwin
- A- 850 lb 'notch' occurred
 - B- Total shear failure at 985 lbs
- Test 2** Approximately 500 lb increase per sec loading
- A- No notch
 - B- Total shear failure at 980 lbs
- Test 3** Approximately 1000 lb increase per sec loading
- A- No notch
 - B- Total shear failure at 975 lbs
- Test 4** Approximately 1000 lbs increase per sec loading
- A- No notch
 - B- Total shear failure at 965 lbs

Fig. 61a. Shear Pin Test Evaluation Data.

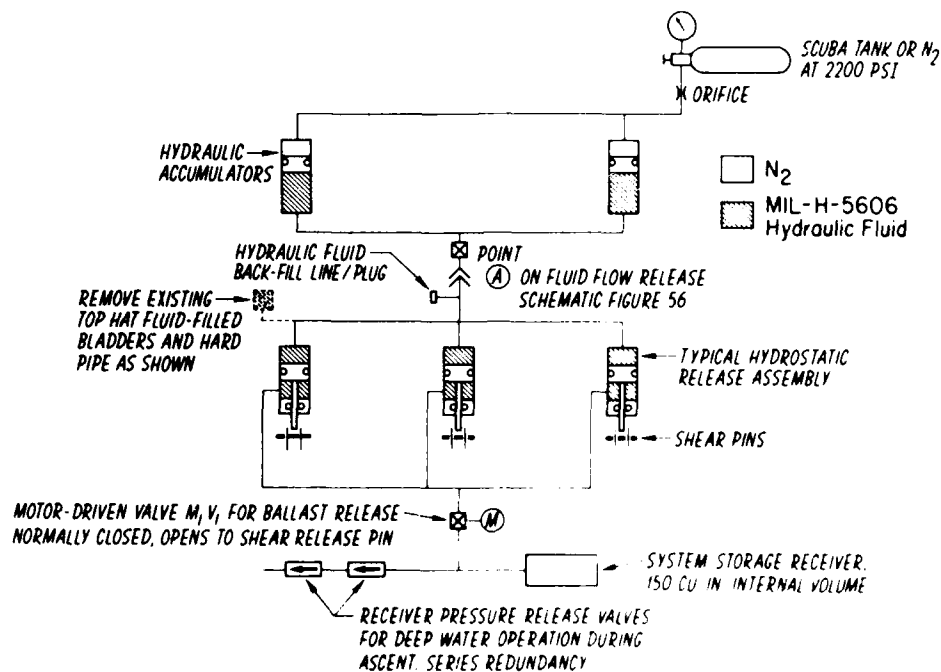


Fig. 62a. Simulated Deep Water Hydrostatic Release Pressurization System

9.1 Water Samplers

The water samplers are manufactured by General Oceanics located in Florida. The one illustrated at the upper right of Figure 63 is a sterile bag, Model 1030. In normal use it samples directly from the test section discharge port, collecting a 1.5 liter quantity from within the Sea Duct. The sampler is triggered hydraulically by the same pulse that releases the closure doors on sediment core recovery.

The other two water samplers are piston and bucket samplers, Model 1240. They obtain water specimens at approximately one and two meters off the bottom. They consist of a main cylinder and a piston or bucket. The piston water samplers collect the sample from the bottom of the cylinder within the one second interval from the time the test section is depressurized. The bucket samplers collect the sample from the bottom of the cylinder and then the closure doors on sediment core recovery.

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SEA DUCT: A DEEP-SEA COMPUTER-CONTROLLED RECIRCULATING

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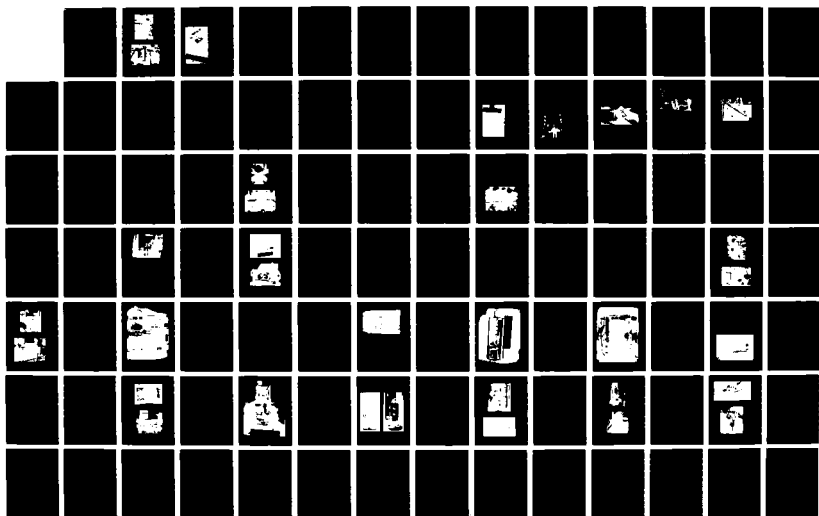
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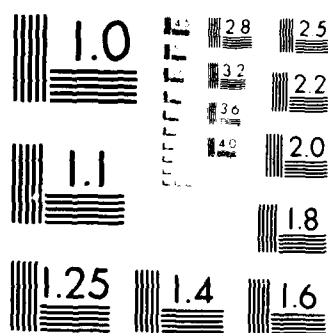
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Fig. 63a. Water Sampler,
Sterile Bag Model #1030

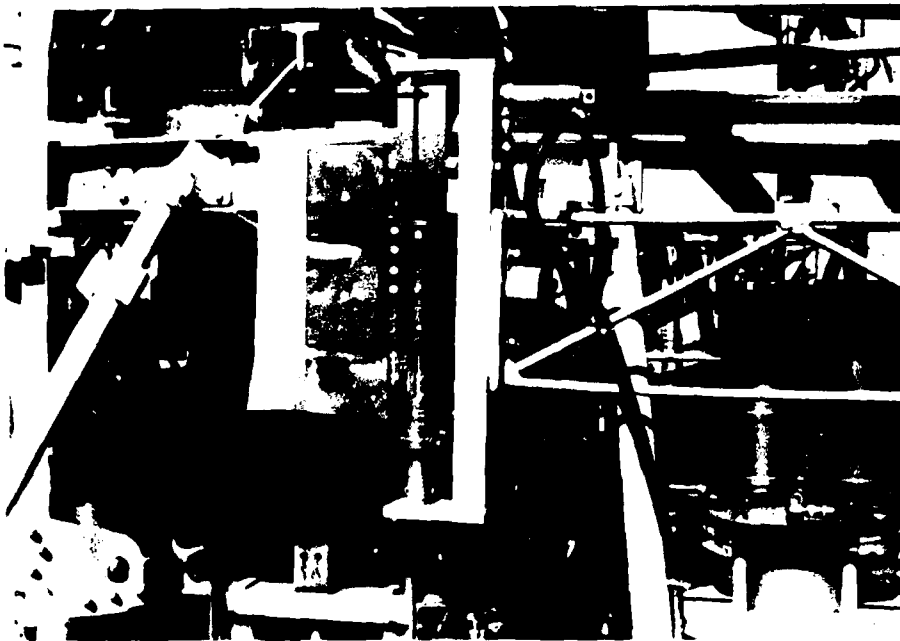


Fig. 64a. Water Sampler, Chopstick Model #1040

9.2 Sediment Core Box Samplers

There are two core sampling devices similar to the assembly illustrated in Figure 65. The sampler will obtain a six inch by six inch core 13 inches long. They are inserted in the bottom sediment by a hydraulic piston. The penetration force generated by the piston is approximately 1200 pounds, with a withdrawal force of 885 pounds.

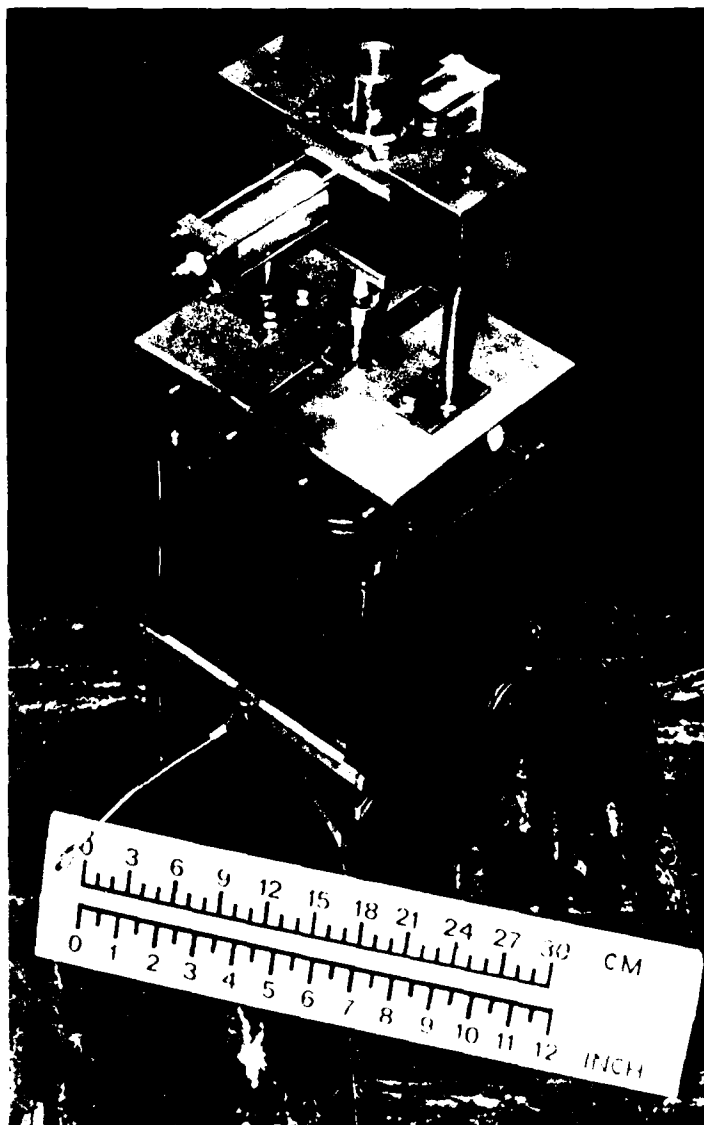


Figure 65a

With the test section of the recirculating system inserted in the sea floor, and depending on the depth of penetration of the Sea Duct ballast feet, the base, or cutting edge, of each core box is approximately 6 to 8 inches off the bottom. The insertion cylinder is capable of a 26 inch stroke, assuring total penetration and a full length sample. The insert/retract rate, or piston speed, can be adjusted by needle valves in the hydraulic cylinders. The present insert rate is approximately one inch per three seconds. The withdrawal rate is

Fig. 66a. Stereo Camera/Test Section Photographic Stop Positions.

slightly higher. The core samplers are similar to those used for sediment collection by the manned Deep Submersible ALVIN.

When the core box is inserted into the sediment, an elastomer flapper valve at the top allows displaced water to escape. When full insertion has been achieved and the unlatch mechanism triggered, eight negator springs power the sliding closure doors that trap and encase the core sample prior to withdrawal. Unlike the submersible version, the unmanned Sea Duct coring device required modification to provide all insert/retract and door closure-unlatch operation to be hydraulic powered. A microprocessor controls the complete sequence of operation for the two sampling devices.

Core sampler #2 is located adjacent to the discharge end of the Sea Duct test section. It is positioned to obtain an unworked sample from outside the test section. Core sample #1 is positioned outside of, and abutting the test section inlet transition section. On completion of the flow test sequence, the test section is retracted and the rotary carousel turned approximately 156 degrees from its original "inserted" position. At this point core sampler #1 can be extended through the sediment to obtain a core from what had been the internal ocean bottom or "worked" sediment at the discharge end of the test section. Its door closure is activated hydraulically, which also triggers the operation of chop stick water samplers #2 and #3. Its insert and retract rate is similar in both operation and speed as the #2 core box. The samplers are completely sealed devices that have been designed to prevent core loss and washout as they pass through the air-water interface at the surface.

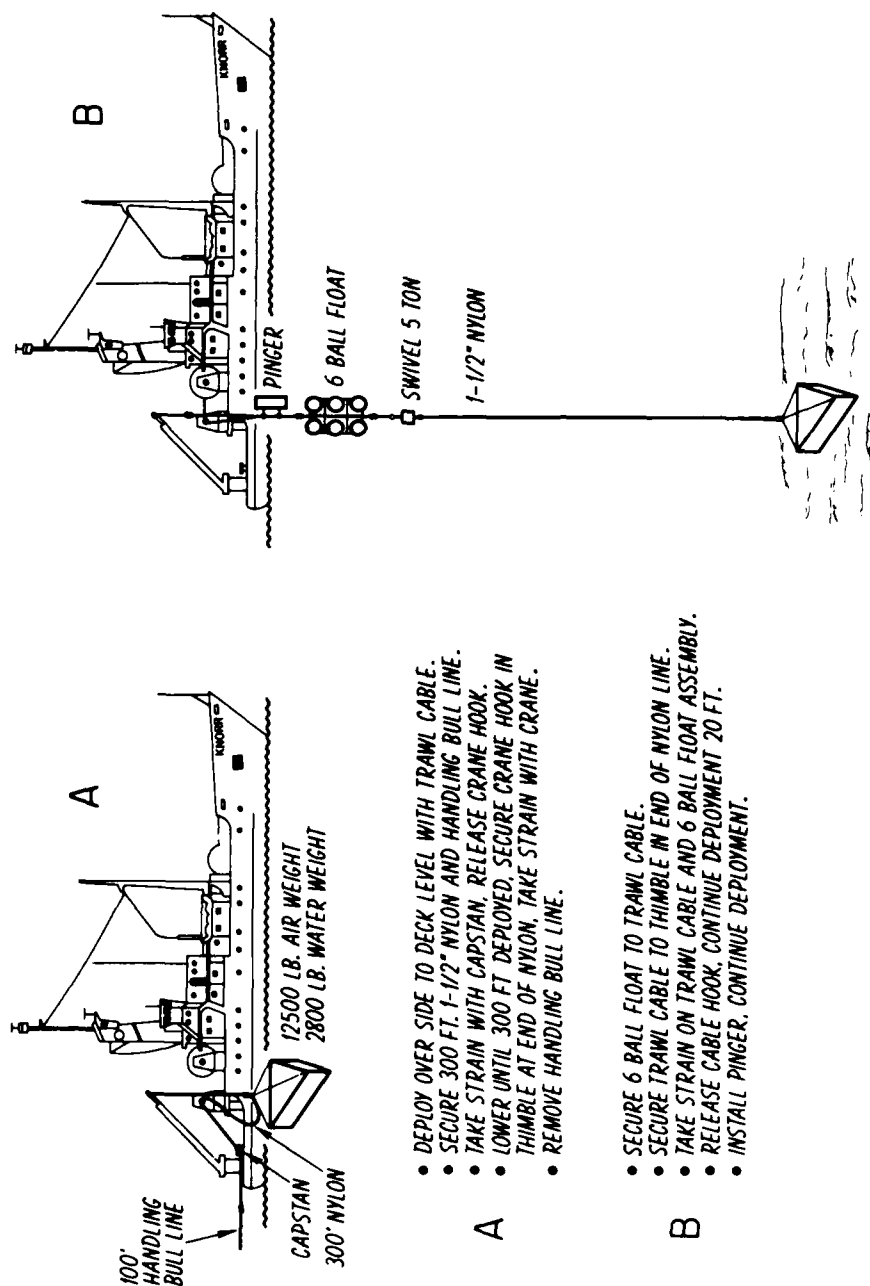


Fig. 67a. Sea Duct Deployment/Trawl Cable Transfer Scenario.

9.3 Stereo Camera System

A self contained stereo camera system is mounted on the longitudinal centerline of the "X" axis traverse carriage. In Figure 22 (X-Y-Z Traverse Carriage), the black truncated cone in the upper center illustrates the camera location. It looks vertically down through the top plate glass viewport of the test section, providing full coverage of the bottom. While it will move with a vertical motion when the "Z" axis carriage is actuated, its focal length has been adjusted for a sharp ocean bottom image when its in the full down position. It traverses along the test section "X" axis from the inlet to the discharge end.

A light-emitting diode is secured to the traveling carriage, with light interrupter tabs attached at four places along the carriage track. The tabs are adjustable and provide a wide variety of camera stop positions. In the present configuration, four camera stop points which are illustrated in Figure 66, provide an approximate 1/2 inch field of view overlap of the ocean bottom within the test section. When the stereo slides are viewed in proper sequence the field overlap provides a mosaic map of the sediment. The camera, photo flash trigger pulse, and the "X" axis motion are primarily controlled by the microprocessor. The actual camera stop points are established by the interrupter tabs.

The camera system, a Model 2000 stereo camera with a 1500 SX strobe light powered by an external battery pack, was procured from PhotoSea System, Incorporated, which is located in California. The camera is a dual lens system encased in a dedicated housing. The single camera dual lens construction eliminates the alignment problems usually associated with a two camera, 35 mm

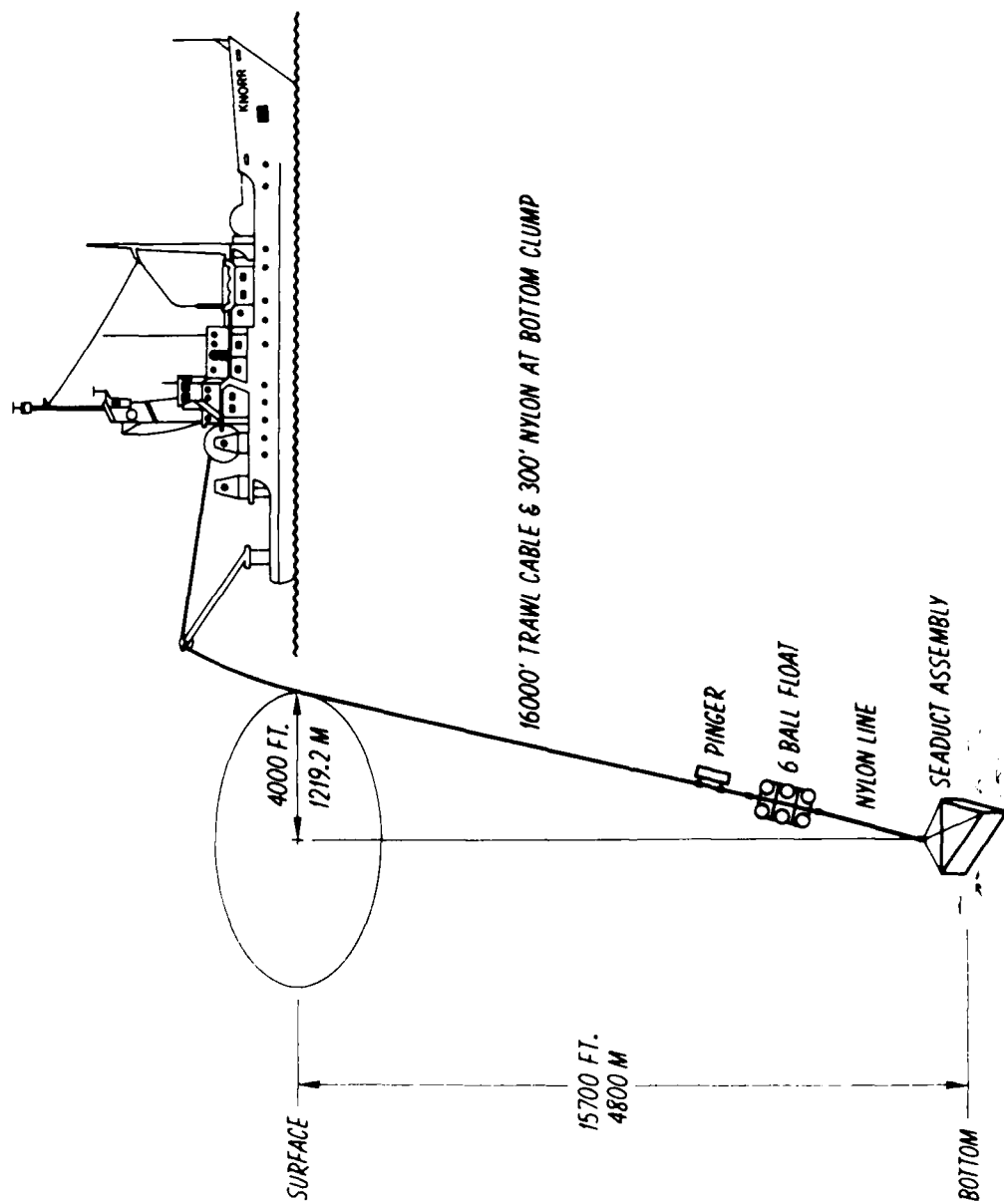


Fig. 68a. Sea Duct Deployment/Hard Wire to Surface Vessel.

stereo system. It provides "depth" perception in the form of stereoscopic viewing for the close-up observation of the ocean bottom sediment within the test section. The pressure resistant housings protecting the camera and its associated equipment are designed for a 15,000 foot depth rating.

The camera's 35 mm film roll yields 100 stereo pairs, or 250 mono frames. This film capacity provides a complete historical sequence of the ocean bottom, from zero flow to the "rework" resulting from the 0.9 knot recirculating sea water flow passing through the test section.

10.0 Sea Duct Deployment/Recovery Procedures

The at-sea handling of the Sea Duct structure requires the use of a crane having an over the bulwark extension of at least 20 feet. The crane's lifting capacity at the required extension must be capable of handling an air weight of 12,500 pounds. From the base of the Sea Duct ballast feet to the three part bridle lift ring is 19 feet. The off-deck vertical lift capability of the crane must be sufficient to lift and swing the Sea Duct outboard while clearing any deck hardware or bulwarks.

As a note of caution, the crane used to deploy the Sea Duct must have sufficient bull gear rotation drive power to safely maintain a fixed over-the-side position after deployment. It must also be capable of safely resisting the side load generated by the bull rope used during the trawl cable transfer procedure. As a point of interest and to determine a load baseline prior to an at-sea deployment, a dynamometer was secured to the capstan with the opposite end attached to the boom. A typical deployment exercise was performed. Boom side loads up to 5000 pounds were generated with satisfactory holding power and no creepage of the crane. It is important to include the

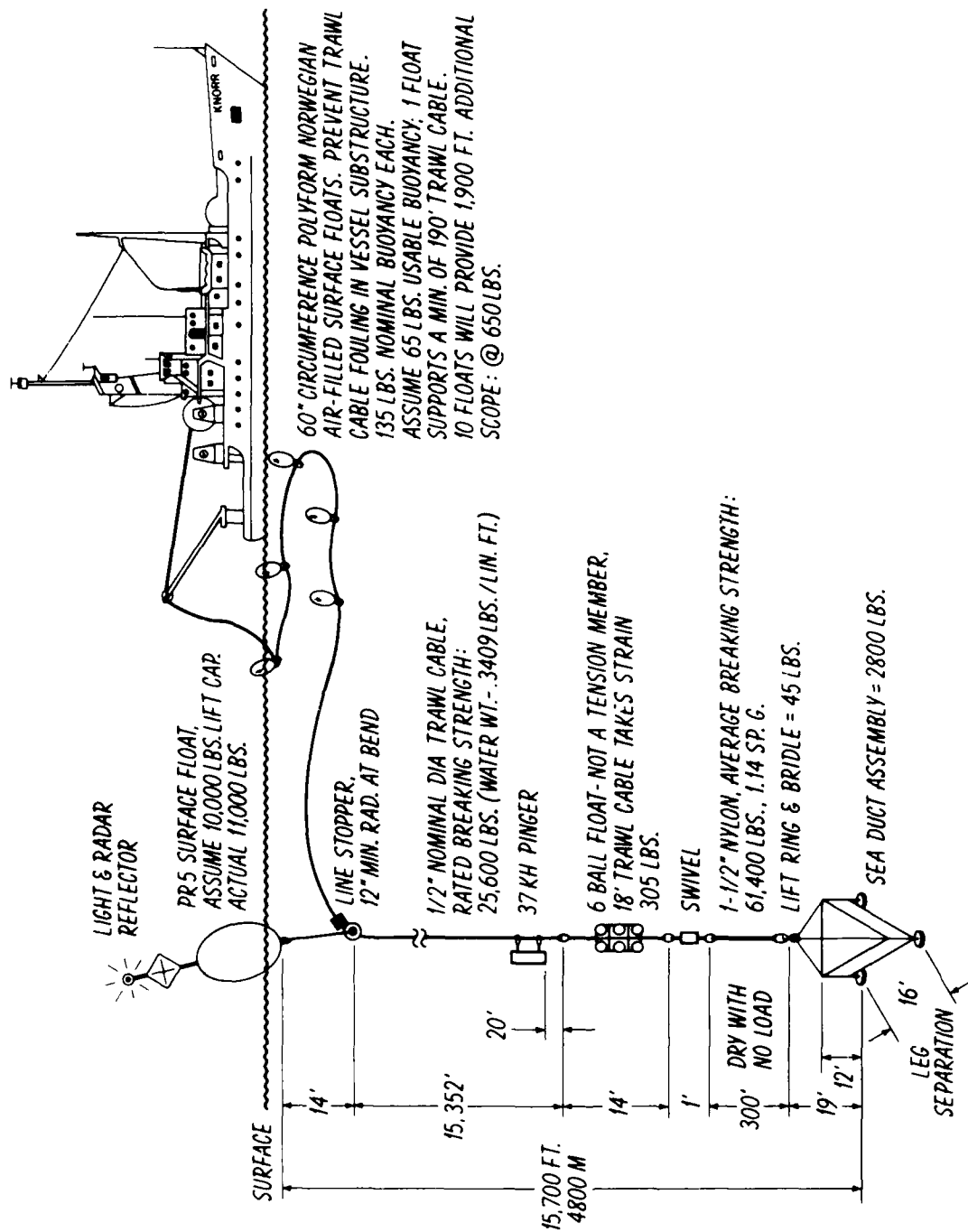


Fig. 69a. Sea Duct Deployment/Surface Float to Shipboard Cable Tether.

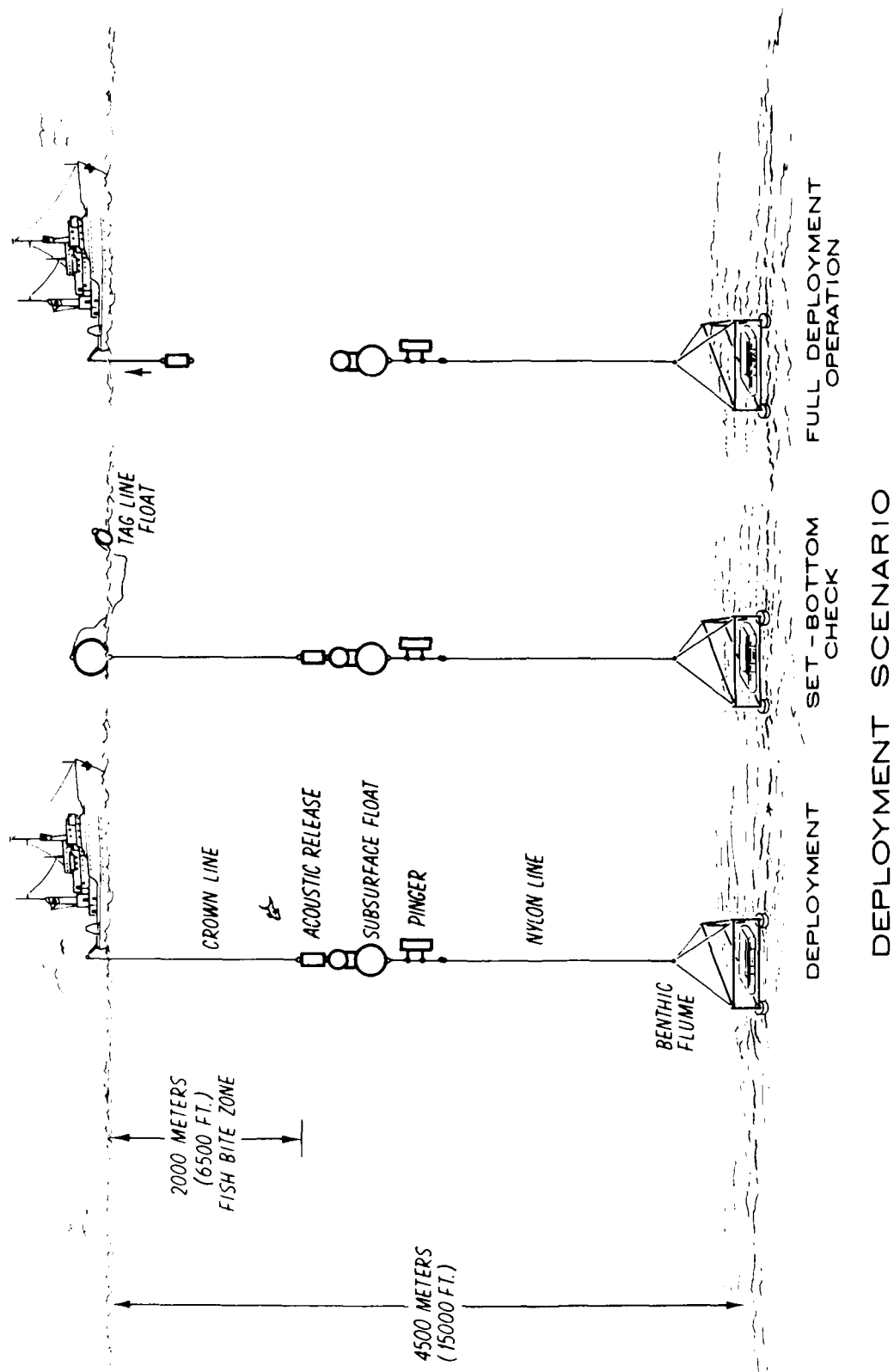


Fig. 70a. Sea Duct Full Release Deployment Method.

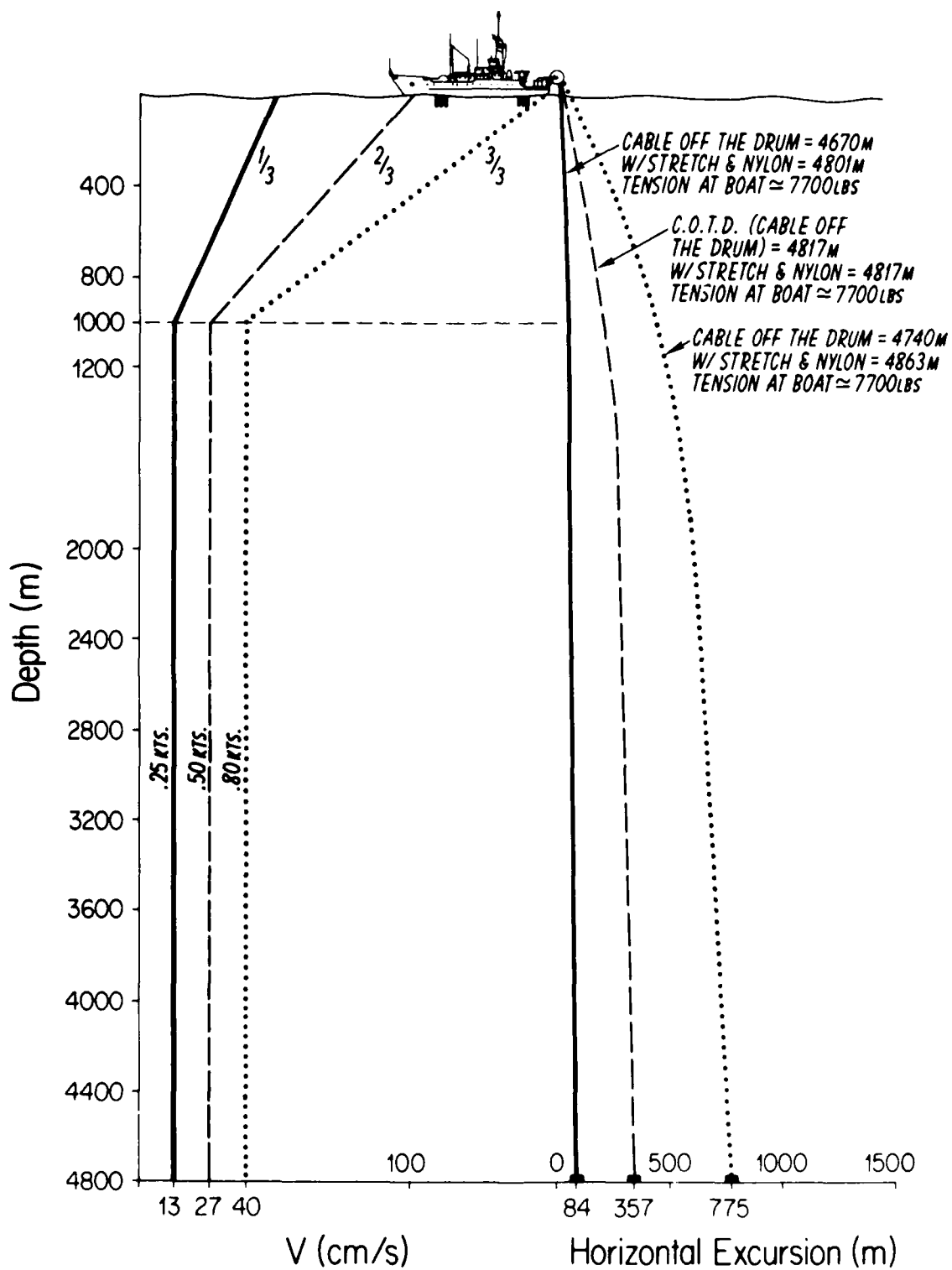


Fig. 71a. Trawl Cable/Nylon Snubber Lengths to Reach Bottom in Various Current Velocities.

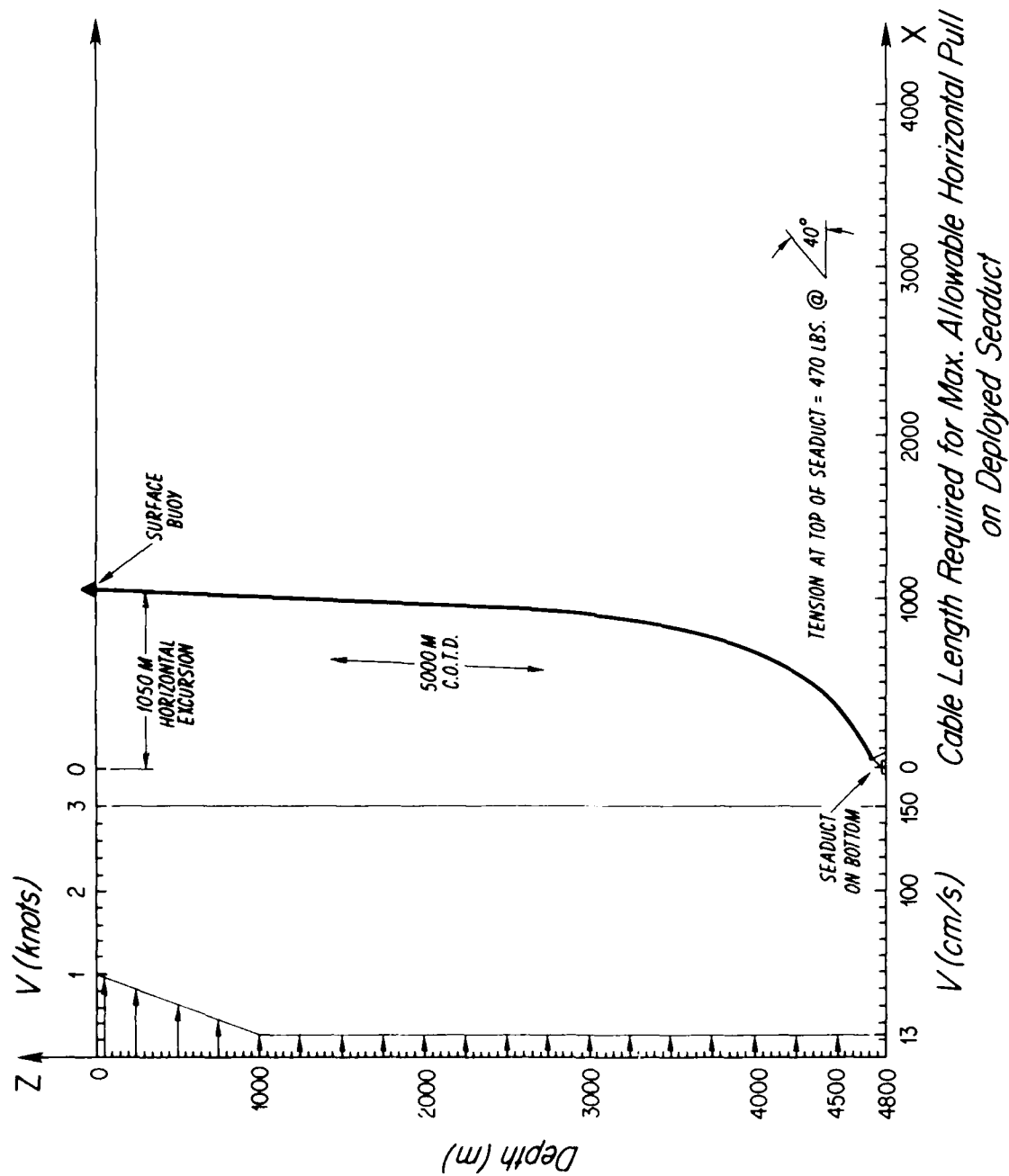


Fig. 72a. Trawl Cable Deployment Length for Maximum Allowable Side Load at 13 cm/sec Current.

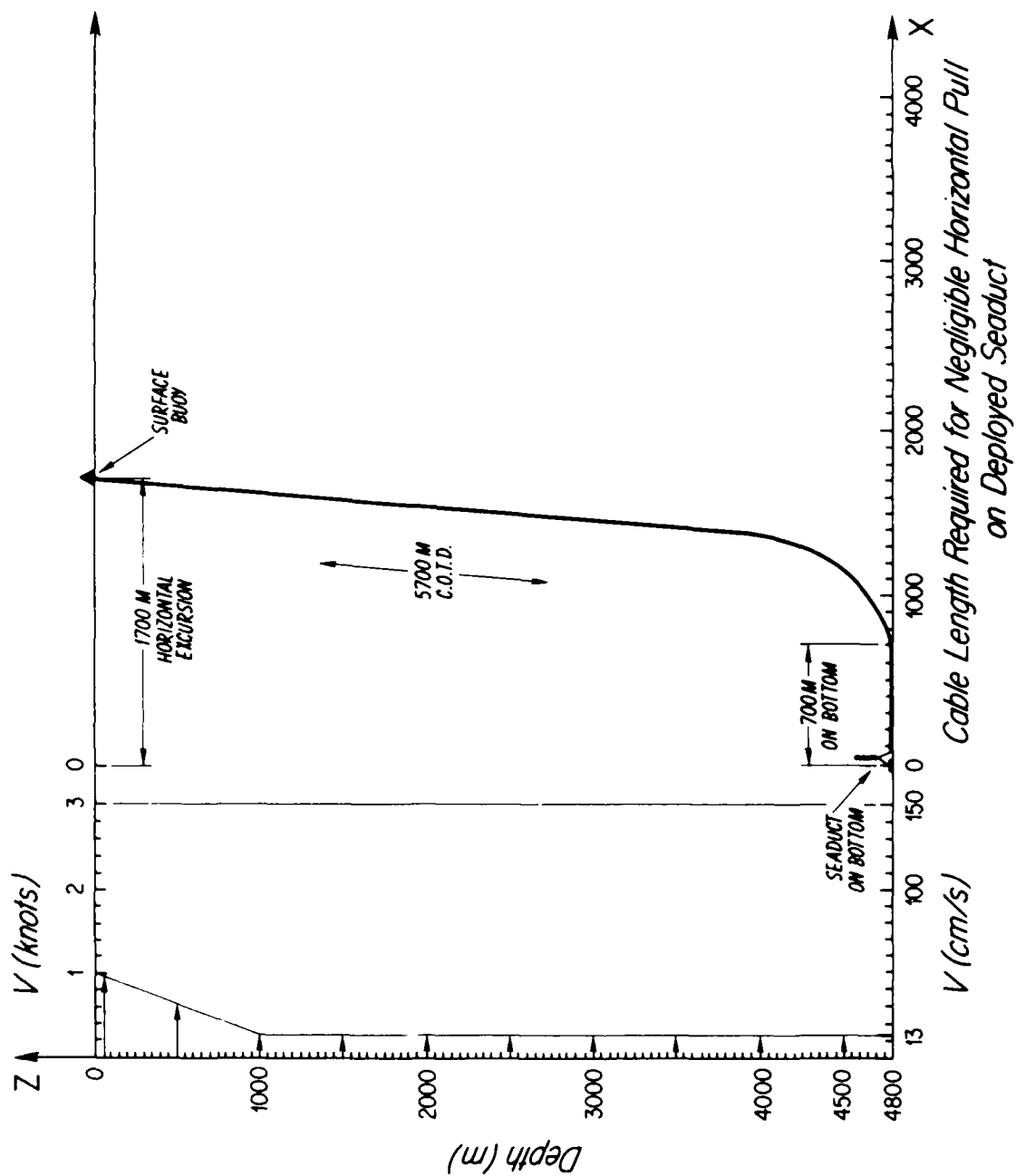


Fig. 73a. Trawl Cable Length for Negligible Side Pull on Sea Duct at 13 cm/sec Current.

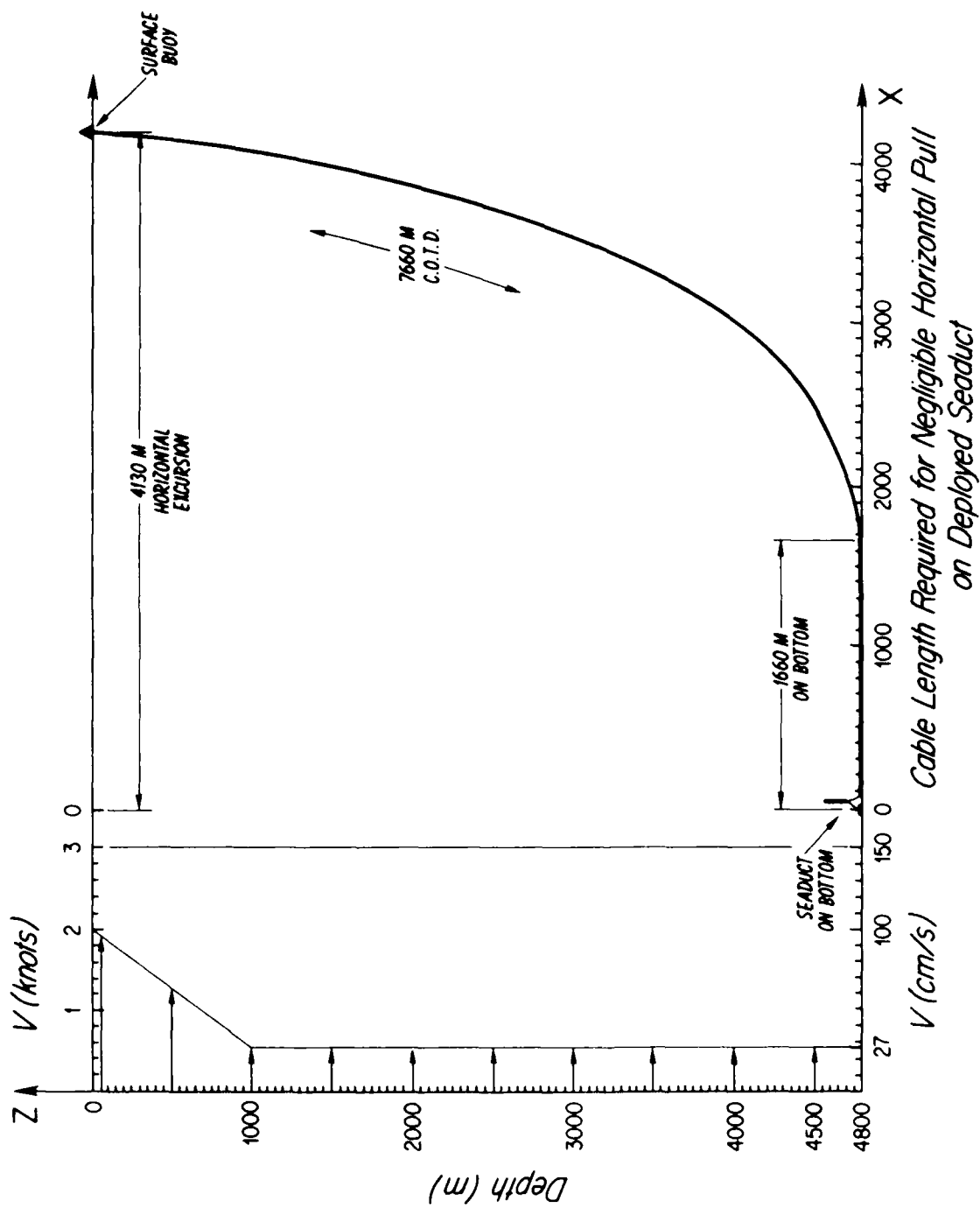


Fig. 74a. Cable on Bottom Requirement at 27 cm/sec Velocity.

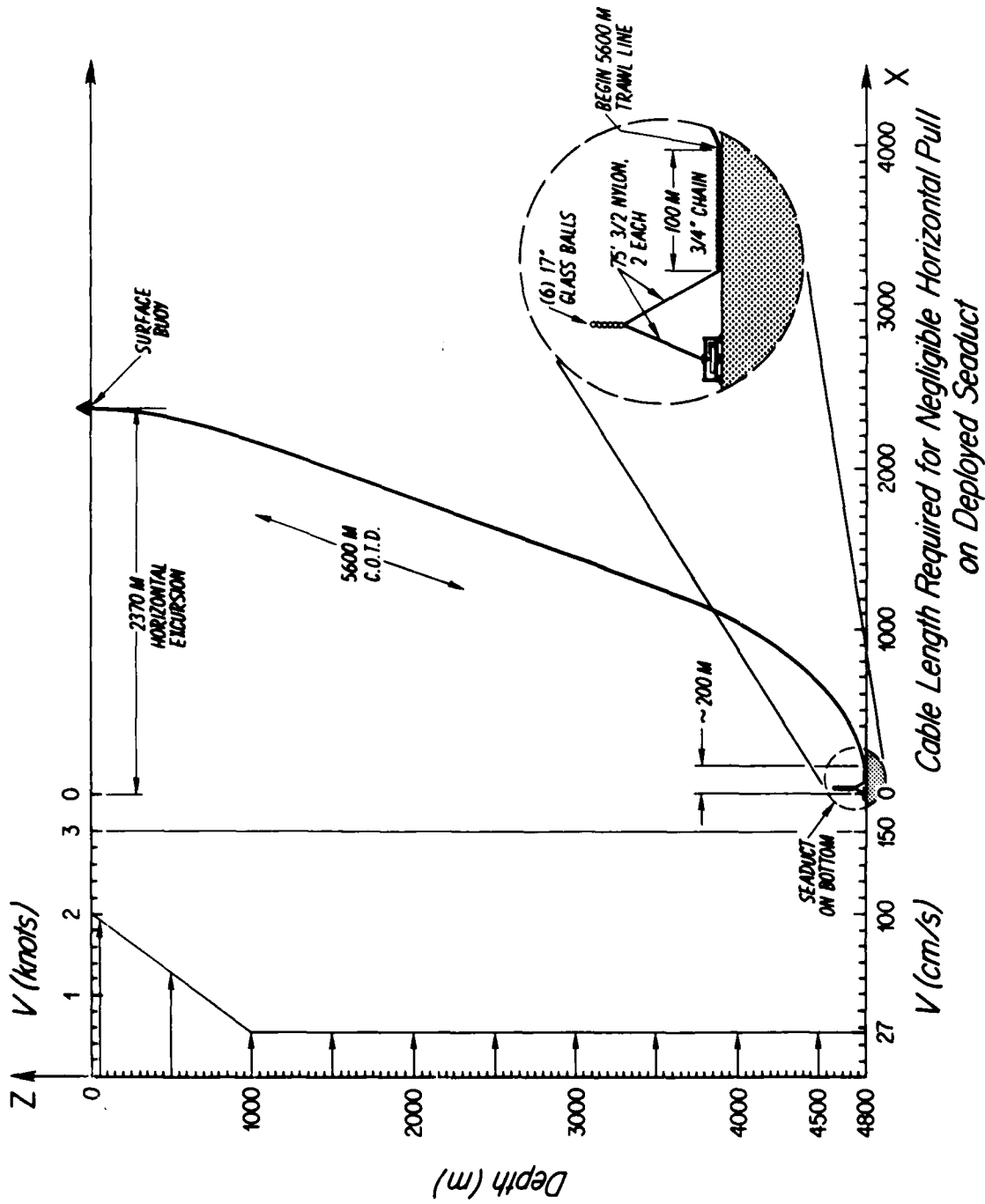


Fig. 75a. Modified Cable/Chain On Bottom Requirement at 27 cm/sec Velocity.

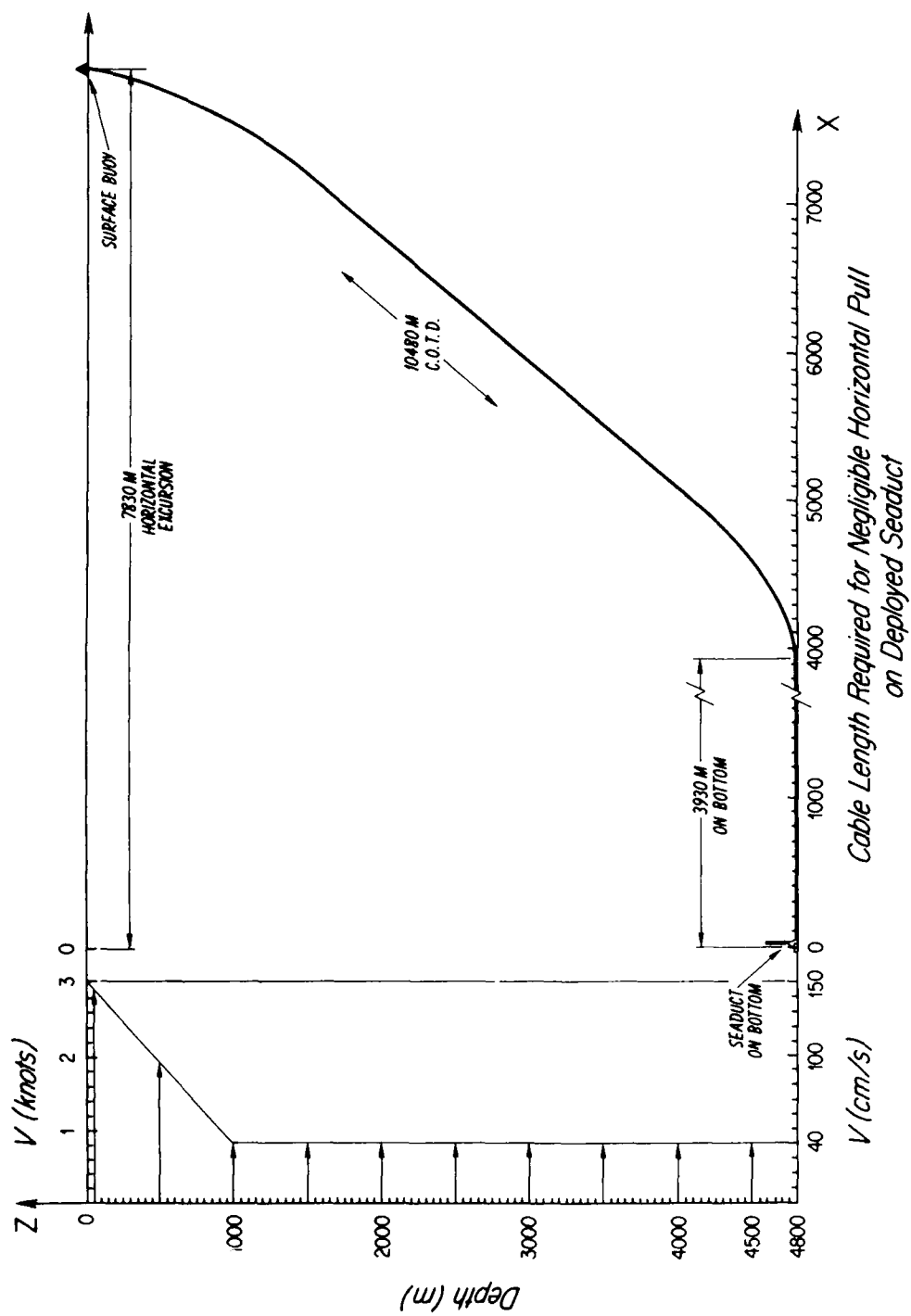


Fig. 76a. Cable on Bottom Requirement at 40 cm/sec Velocity.

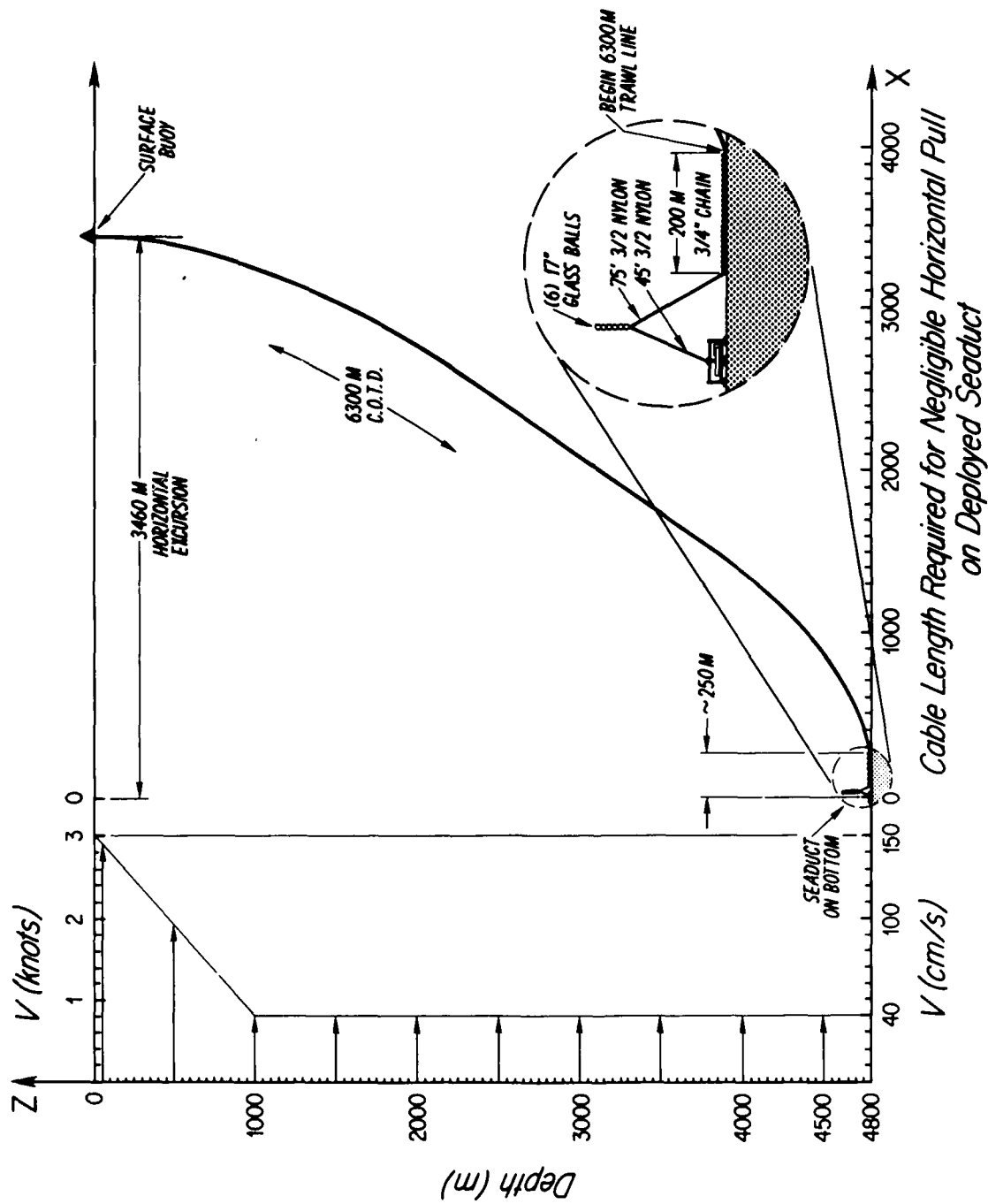


Fig. 77a. Modified Cable/Chain Requirement at 40 cm/sec Velocity.

length of boom extension and bull rope fleet angle from the capstan to the boom sheave when making the load calculations.

In preparation for an at-sea deployment, several operational scenarios were proposed. Figure 67 illustrates the off-deck into water, with bull line transfer to trawl cable operation. Figure 68 depicts a deep water deployment hard wired to the surface vessel, while Figure 69 illustrates a buoyed off, but ship secured approach. The final sequence shown in Figure 70 illustrates an "on its own" deployment. This scenario would be used only after sufficient deep water deployments demonstrated that all back-up safety and recovery mechanisms had a 100% reliability factor.

10.1 Tether Cable Drag Characteristics

In order to determine the forces that could result in Sea Duct tip over or bottom liftoff as a result of current induced side loads on the deployment cable, a computer program was developed by the Ocean Engineering Structures and Mooring Section. The program included expected cable catenary for various surface currents, as well as proposed cable lengths to reduce side tip-over loads to acceptable levels.

Calculations disclosed that a 1400 to 2000 pound horizontal pull at the lift ring could slide the Sea Duct along the bottom. With mud prongs installed on the feet and firmly embedded in the bottom, it would require approximately 1000 pounds of horizontal pull to tip the Sea Duct structure. Figures 71 through 77 provide the user with the minimum on-bottom cable or chain layout required to maintain an acceptable side load on the Sea Duct. The charts cover current velocities from:

SURFACE	DECREASING TO	AT DEPTH OF
1.0 knot	13 cm/sec (.25 kt)	3300 feet (1000 meters)
2.0 knot	27 cm/sec (.5 kt)	3300 feet (1000 meters)
3.0 knot	40 cm/sec (.8 kt)	3300 feet (1000 meters)

For calculation purposes, it is assumed that the current profile starting at the 3300 foot depth to the bottom remains constant, as illustrated by the vertical velocity line on the various charts. The length of cable or chain on the bottom is calculated to maintain a side load pull on the Sea Duct that is less than 470 pounds at the lift bridle ring. The abbreviated C.O.T.D. shown on the charts as the cable below the buoy line provides the winch operator with the "cable off the drum" requirements, and would include cable on the bottom.

Several proposed "bottom clump" modifications are illustrated as possible means of reducing the amount of unloaded trawl cable stretched over the bottom. The cable is 3 X 19 X 1\2 inch right hand lay, galvanized construction, with a safe working load of 11,500 pounds at a safety factor of two. It is designed to be rotation free, and has a rated breaking strength of 25,600 pounds. In addition, the Sea Duct lift bridle provides a ball bearing swivel assembly to reduce twisting of the winch cable during deployment. From a practical standpoint however, it is not considered good practice to lay unloaded cable on the bottom. The possibility of instantaneous formation of hackles or kinks as the load is removed will damage the cable beyond repair. When recovery is attempted, the weakened cable could part as it picks up the load of the Sea Duct water weight. Depending on the kink location, it could also prevent the successful recovery of the device by preventing a complete rewind on the winch drum.

10.2 Decoupling of Acceleration Stress

In order to reduce the stress on the trawl cable during pitch and roll of the surface vessel, a 100 meter length of 1 1/2 inch braided nylon line is secured between the Sea Duct and the cable. It has a breaking strength of 61,400 lbs. Its inherent stretch and recover characteristics provide surge relief between the Sea Duct and the essentially stiff deployment cable.

While the Sea Duct structure appears open, its measured flat plate surface area is 158.9 square feet. On site deployment tests indicate the device can be deployed at rates as high as 50 meters per minute without cable overrun. Actual deployment rates were established at a conservative payout speed of 35 to 37 meters per minute.

A cable tension dynamometer and strip chart recorder measured slow, undulating excursions starting at a baseline of 3000 lbs. to as high as 4500 pounds. Excursions on the negative side of the baseline indicated line tension as low as 1500 pounds. The load level peaks and valleys remained reasonably constant throughout the deployment, closely following the pitch and roll of the surface vessel. On recovery, the baseline moved to 3500 pounds, with a haulback rate between 35 and 37 meters per minute. Excursions in the positive mode were as high as 5125 pounds; the loads on the negative side during a ships roll indicated a 2000 pound load. The baseline discussed in this test will vary directly with the length of cable deployed. For the purpose of calculations, the cable water weight is 0.3409 pounds per linear foot.

Referring to Figure 69, a typical surface buoyed, deep water ship-secured deployment, and Figure 72, a current profile for a one knot surface velocity, the following cable loads can be expected at the winch. Note the one knot

surface current tapers off to 13 cm/sec at a depth of 3281 feet (1000 meters) and remains at this velocity all the way to the 4800 meter botto . The cable catenary that results from the current side load requires 16,405 feet (5000 meters) of cable off the drum to reach the bottom. The cable load baseline at the winch would be 5600 pounds. Depending on the sea state and because of the ships roll and pitch, load fluctuations will oscillate around both sides of this baseline.

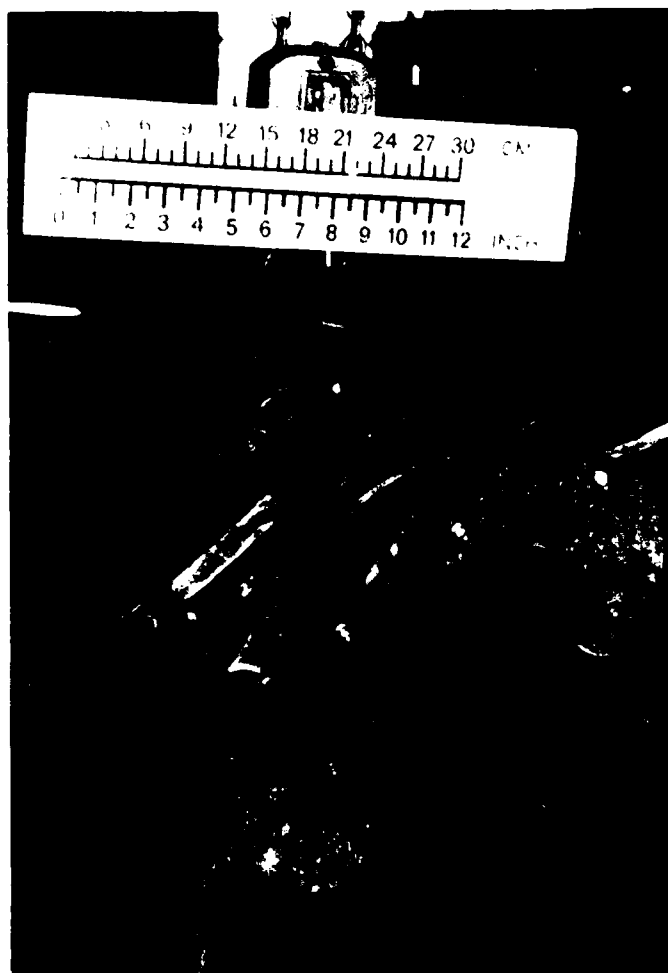


Fig. 78a. Trawl Cable Surface Float Stopper

The surface float selected for the deployment is a Model PR5 closed bottom, air inflatable device with 11,022 pounds of flotation which provides an approximate 2 to 1 safety factor. It has an adjustable relief valve to prevent over pressurization; its present setting has been adjusted at 2 PSI. The unit is available from the Automarine Corp., Chappaqua, New York. If additional flotation is required, a Model PR10 with 22,040 pounds of flotation is available. The physical size of the larger model is considerably greater than the PR5 and might result in deck handling problems.

The line stopper shown beneath the float in Figure 69 must be capable of handling the weight of the deployed cable. The unit selected was a Mid-Line wire rope clamp Model 16511 for 1/2 inch diameter cable. It was modified to provide a smooth off the clamp fairlead having a twelve inch radius. The cable guide reduces the possibility of a sharp cable bend and subsequent kink. Figure 78 illustrates the stopper with the trawl cable clamped between its jaws.

10.3 Recovery Discussion

When recovery has been initiated and the Sea Duct approaches the surface, the six ball floats and pinger are removed (Figure 79), and the bull line secured to the 100 meter length of nylon. The Sea Duct is brought the re-



Fig. 79a. Six Ball Float Removal

maining way by the bull line and capstan. The final recovery of the Sea Duct structure requires a powered Zodiac or other soft and highly maneuverable surface craft, with complete and careful co-ordination between the recovery crew, crane operator and the people in the Zodiac. Referring to Figure 80, the Sea Duct lift ring has just broken the surface. The crane lift hook is lowered and secured to the ring by the boat crew. A

strain is taken on the cable by the crane operator, who is cautious not to lift the Sea Duct because of its possible entanglement with the Zodiac.

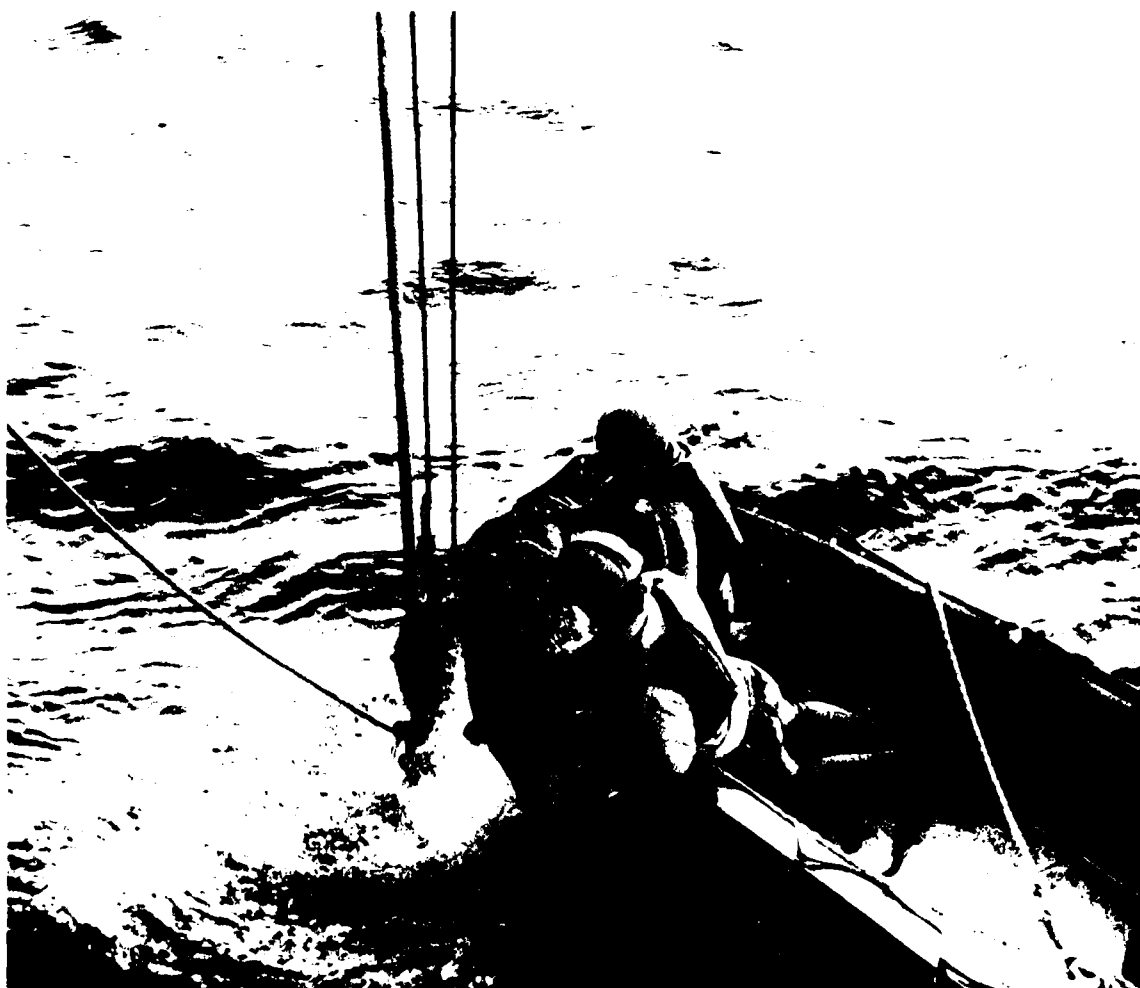


Fig. 80a. Initial Crane Attachment of Sea Duct at Air/water Interface

The Zodiac crew must now disconnect the shackle securing the Sea Duct to the relaxed 100 meter length of nylon. At this point they back off and the crane lifts the structure until the handling rings are exposed. Tag lines are secured to the rings by Zodiac personnel, and the recovery crew begins to snug the lines. Figure 81 is a typical deployment/recovery operation, illustrating the numerous tag lines and block and tackle sets required.

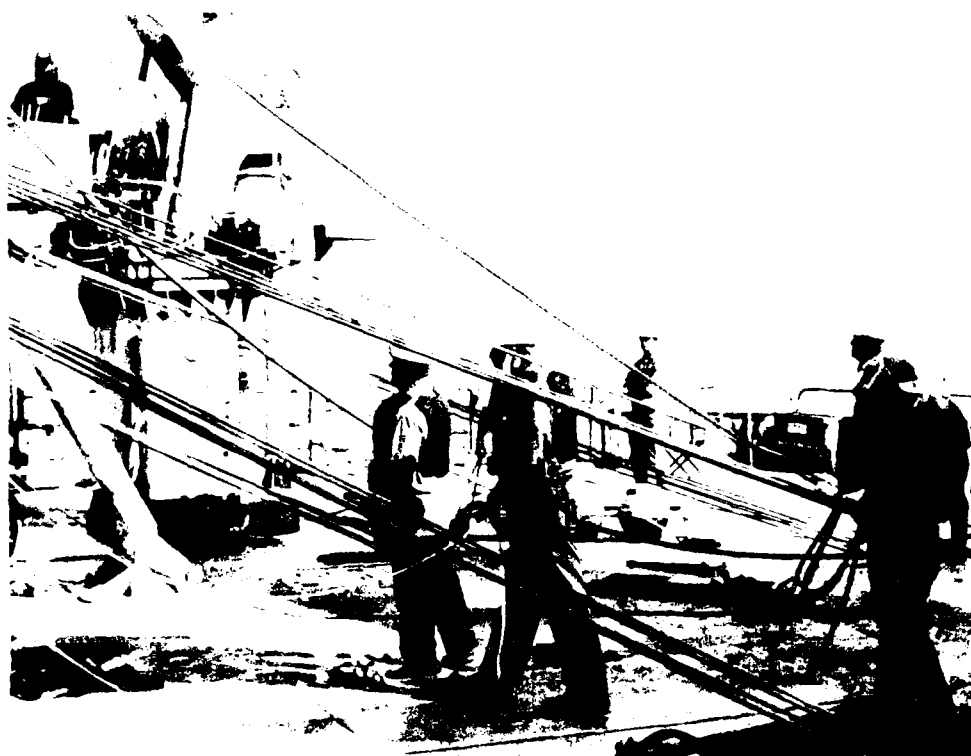


Fig. 81a. Block and Tackle Deployment/Recovery Procedure

Close co-ordination between the recovery crew and crane operator is mandatory at this point. As the crane moves the Sea Duct inboard, the block and tackle crew must maintain a constant strain on all circumferential tag lines to prevent the structure from entering a pendulum mode. Six tons of suspended structure rocking athwartships as the ship rolls is an awesome sight to those observing, and most frightening to those close in.

While not visible in the Figure 81 photograph, the block and tackle tag lines used during deployment can be released remotely from the Sea Duct by shipboard personnel. The tag line release is accomplished through the use of a "grease stick", which consists of a release line and stainless steel pin that is inserted through a single part that bends through one tag line eye. Each tag line is secured to a handling ring on the Sea Duct structure as

shown in Figure 82. The hook on the traveling, or running block, is secured to the free eye on the tag line. Each block and tackle is a five part device with a free length of 35 to 40 feet. They are all rove to advantage. Assuming a full 12,500 pound steady pull on a single tackle, the hauling part could see a load as high as 2500 pounds.

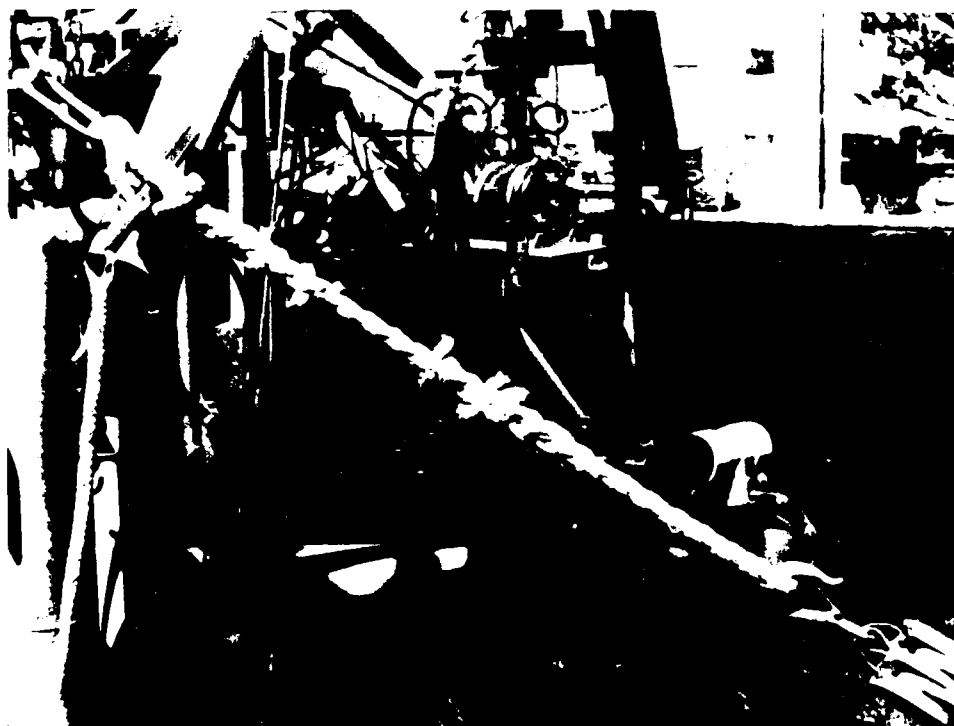


Fig. 82a. Tag Line "Grease Stick" Release

The grease stick release was used on all block and tackle tag lines, and at the main lift ring on the Sea Duct bridle. During deployment and at the appropriate time, the strain is removed from a block and tackle hauling line, and the grease stick pulled out of the tag line freeing the Sea Duct from its deck restraints. This procedure is repeated until all handling lines are released and the lift ring has been transferred to the trawl cable.

Once onboard, the Sea Duct is given a through washdown with potable water; battery gas vents are installed, and all water sumps are drained and

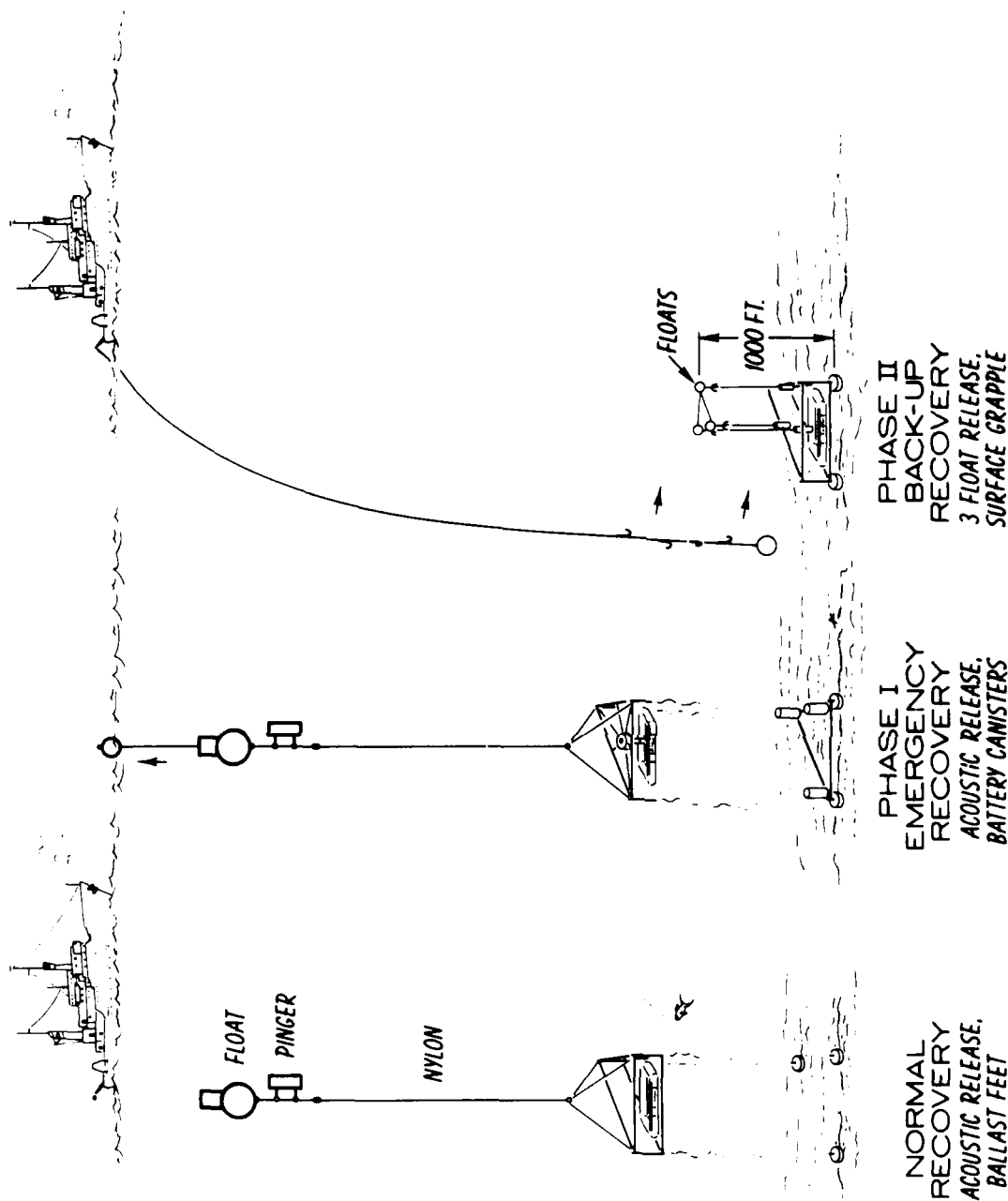
inspected for sea water intrusion. The elastomer top hats are semi-transparent and readily show if any sea water has entered their particular system. The water and sediment samples can be either removed in their entirety, or the specimen itself can be transferred to another container. The lead acid battery packs are put on charge. For a normal on the bottom operation of five hours, the battery system can be brought up to full charge in approximately sixteen hours. The battery packs are charged individually, with five hours of dedicated charge time allocated to each.

The microprocessor and LDV data tapes are removed for data reduction, and the stereo camera is brought to the laboratory for removal of the film pack. The photo flash and camera batteries are put on charge and fresh film loaded in the camera. The lead acid battery packs are not topped off until just prior to launch, as ambient temperature changes and battery charging results in burping out up to a quart of compensation oil from each pack.

10.4 Emergency Recovery Discussion

The emergency release systems were predicated on the Sea Duct, eventually becoming either a free fall device and/or a cable deployed system that could be acoustically released for a long term bottom deployment. In view of the experience gained from the ocean deployment in 1986, it would appear that bottom operational or data gathering periods in excess of five hours are not required at this time.

Emergency systems however, have been built into the Sea Duct and are available for future long term programs. The mechanics of the release mechanism is covered in Section 8.0, entitled **Hydrostatic Release Systems**. The rationale for, and the proposed methods of accomplishing the two emergency steps illustrated in Figure 83 will be covered in this Section.



RECOVERY SEQUENCE

Fig. 83a.

In its present configuration the Sea Duct has a water weight of 2,800 pounds. In order for the emergency backup recovery procedures to become operational, additional buoyancy will be required. To overcome this condition, it would require 103 cubic feet of 38 lb/cubic foot density syntactic foam, or 50 seventeen inch glass floats. The present air weight of Sea Duct is 12,500 pounds; the addition of 103 cubic feet of syntactic foam increases this to 16,400 pounds. If glass spheres are used, the air weight becomes 14,860 pounds. With either method we are beginning to expose the lift bridle, its attachment hardware, and the foam filled tubular structure to considerable added stress.

This does not mean however, that the added flotation must be secured to Sea Duct itself. There is no reason it couldn't be attached as a separate package after Sea Duct is in the water. Not easy, but not impossible either.

A second approach to reduce the water weight might be to lighten the existing lead acid battery packs through the use of a high density power source. The present batteries have an air weight of 1700 pounds, with a water weight of 800 pounds. If this was reduced by one-half, it would lower the air weight and the flotation requirements substantially. The Sea Duct structure will never become an easy at-sea handling operation. However, through judicious use of weight reduction methods, it is possible for it to be cable deployed with a free ascent recovery.

As illustrated in Figure 83, the normal method for accomplishing a free ascent would be to release the three cast iron foot pads. The pads shown are fourteen inches in diameter and three inches high, with an approximate air weight of 110 pounds, and a water weight of 80 pounds. Their simultaneous

release provides 240 pounds of positive buoyancy. As a point of interest, all hydrostatic release systems are designed to not only shear the fiberglass restraining pins, but to "kick" the object away from the female cone by a rapid three inch extension of the piston rod.

In the event there is an electro-mechanical or hydrostatic failure of the foot pad release mechanism, a separate emergency system can be activated to drop the three battery packs, providing a net gain of 800 pounds of positive buoyancy.

As a last resort recovery effort, three seventeen inch glass floats can be released. Each float is secured to 1000 feet (300 meters) of 1/2 inch, 2-in-1 braid Sampson nylon-polyester line, which has an average breaking strength of 7500 pounds. Figure 84 illustrates a typical fiberglass storage canister, glass sphere float, and the conical shear pin release cylinder to the right. Some thought was given to the possibility of securing the three lengths of nylon in series, providing a 3000 foot length of line floating above the stricken Sea Duct. The added length would make an easier target for the surface vessel to hook onto. Further discussion leaned toward system redundancy, using three individual float and recovery lines.

For the most part, glass floats have an excellent safety record, although they have been known to implode at depth. The use of three individual, widely separated floats would provide a comfortable backup in the event of a sphere failure. The wide separation reduces the possibility of sympathetic implosions between close proximity spheres, greatly enhancing system redundancy.

While it was not accomplished during any of the 1986 deployments, it is expected that the present fiberglass shear pins in the emergency float system

will be replaced with magnesium rods of the same dimensions. In the event of total system release failure, the magnesium rods would eventually corrode through, releasing the three float and recovery line assemblies. Based on the physical appearance of several magnesium release links used with other systems on the Sea Duct, it is reasonably safe to assume they would reach failure over a three to four day period during constant exposure to sea water. Actual tests will be performed to ascertain the average time required to failure.

11.0 Engineering Improvement and Modification Discussion

The at-sea deployment of the Sea Duct has uncovered several operational, system, and individual component deficiencies that need correction. This section will cover specific items of hardware that either have been modified or still require additional testing, redesign, or replacement prior to another series of deep water deployment cruises. The changes to be discussed will enhance the system operation and data gathering ability of the device.

11.1 Stereo Camera System

In shallow water deployment the entrapment of air bubbles on the recessed face plate of the camera housing has a detrimental effect on the quality of the stereo slides. While the slides provided a sharp image of the bottom sediment within the test section, they were randomly spotted with small bubbles that appeared as white spots, approximately 1 mm to 3 mm in diameter. On diver supported deployments, the bubbles were minimized by waving a hand under the face plate cavity until the majority of them were dissipated.

As a fix, six equally spaced 1/8" slots were milled in the face plate mounting ring to a depth immediately adjacent to the outer surface of the

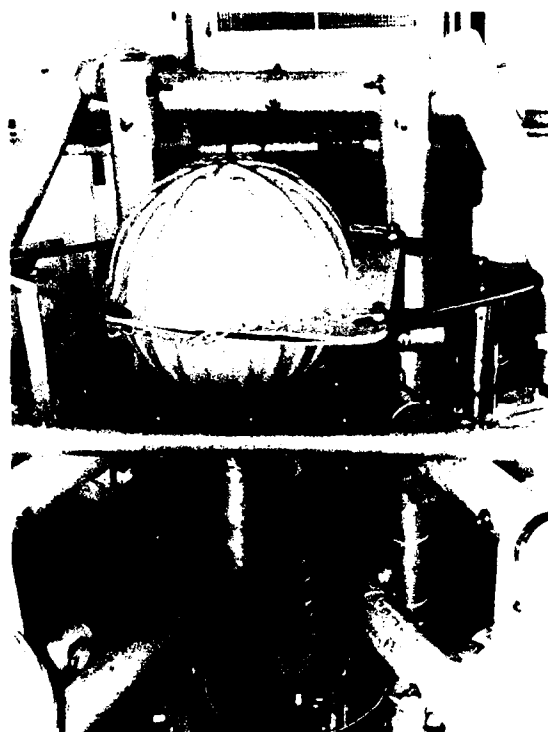


Fig. 84a. Typical 300 Meter
Emergency Grapple Line
Storage Canister and
Float Assembly

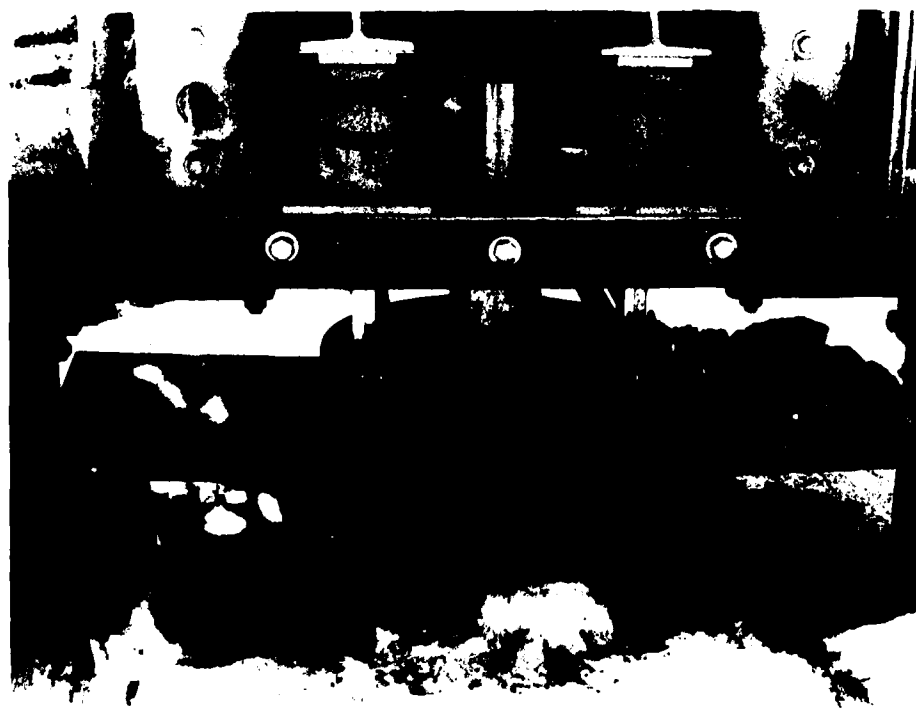


Fig. 85a. Supplemental Ballast Weight Foot Pads and Mud Forks

glass. There were no additional shallow water tests scheduled and the result of the modification is not known. As expected, the film exposed during the 900 foot (275 meters) and 15,750 foot (4800 meters) deployments did not exhibit the air bubble spotting tendency.

11.2 Ballast Weight and Foot Pad Settling

Deployments conducted in sediment conditions of soft, unconsolidated clay presents several pronounced problems. The average surface area of each foot pad is 154 square inches, or slightly more than 1 square foot. The 2800 pound water weight of the Sea Duct structure imposes a contact loading of approximately 930 pounds at each foot pad. Diver observations of Sea Duct landings in silt covered sandy bottom conditions showed negligible settling. Landing in soft, soupy bottoms however, indicated mud lines on the structure as high as 14 to 18 inches above the bottom surface of the ballast weight foot pad.

In an effort to reduce the settling of the feet, helper plates in the form of a simple 30 inch X 14 inch X 1/16 inch thick steel sheet was secured to the base of the three cast iron ballast weights (Figure 85). The 2800 pound water weight of the Sea Duct has not appreciably changed, but the foot pad loading has been reduced to 310 pounds per square foot. On the next deployment a considerable reduction was noted in the mud line level. It did not completely cure the problem, but at the time it was considered as marginally acceptable. Although the flat plate surface area of the Sea Duct had been increased by approximately 6 square feet, it did not appear to have a detrimental effect on the original deployment rate of 35 to 37 meters/minute.

It is of the utmost importance when operating in soft sediment of the type experienced during the 1986 cruise to reduce Sea Duct settling to an

absolute minimum. The base of the test section cookie cutter is between seven to nine inches off the bottom when the foot pads land on a firm surface. Excessive foot pad penetration will prevent the carousel from turning, with possible mechanical damage to the test section or the rotary drive.

It is proposed that a set of 1/16 inch thick foot pads be fabricated with a 30 inch X 43 inch overall dimension. This is the maximum size that will comfortably fit between the two mud forks shown in Figure 85. The additional foot pad area will reduce the loading to 103 pounds per square foot. The decreased loading should substantially reduce penetration and assure that the carousel and test section will rotate freely without sediment interference. The rate of deployment must be carefully observed with the increased surface area to assure that the off-the-drum cable is not overrunning the Sea Duct structure's normal sink rate.

11.3 Test Section Top Viewport Cleaner

With the exception of the shallow water diver test series in the Buzzards Bay area, all other stereo film slides of the ocean bottom contained within the test section were of poor quality and unreadable.

The extremely soft bottom at the selected deployment sites and the excessive penetration of the ballast feet put sufficient sediment in suspension so that some sediment settled on the top viewport, effectively blanking out the camera. It is also recognized that either free fall or a cable deployment will have a bow wave of sufficient magnitude to cause some sediment disturbance on contact. However, if the test section remained clear of the bottom, the built-in system delay would allow the general area to clear itself of the sediment cloud before test section insertion was initiated.

The insertion rate of the test section is designed to be extremely slow in order to avoid as much sediment disturbance as possible. Depending on the ambient temperature and hydraulic fluid viscosity, the approximate rate of test section travel toward the sea bed is 1.25 inches/minute - a nice slow approach that will reduce or even eliminate any bow wave formation. Regardless of the slow insert time, we do know a certain amount of sediment will be disturbed and settle out on the top viewport. To correct the condition, a simple motor driven sea water pump, a linear shower head with numerous drilled discharge ports, and a stiff bristle brush should be secured to the X-Y-Z traverse carriage. By running the full length of the test section, the water stream and brush should loosed any sediment adhering to the glass, while the return trip will provide a final flushing.

11.4 Rotary Carousel Trolley Assembly

The present carousel trolley illustrated in Figure 13 consists of four plastic oil-filled ballbearing wheel assemblies secured in a fixed position to the cheek plates. The 'I' beam track is a rolled and welded assembly that is neither perfectly round nor flat; it is not a machined component. Despite careful adjustment of the present design, it is impossible to have all four wheels in perfect contact with the 'I' beam flange. In addition to this problem and at some point during the 1986 dive season, salt water entered several bearing assemblies damaging the internal mechanism to the extent that the carousel was unable to rotate.

It is the writer's opinion that the trolley requires a complete re-design in order to work "with" the built-in distortion of the carousel 'I' beam. One suggested method would be to use a single set of wheels, mounting them on

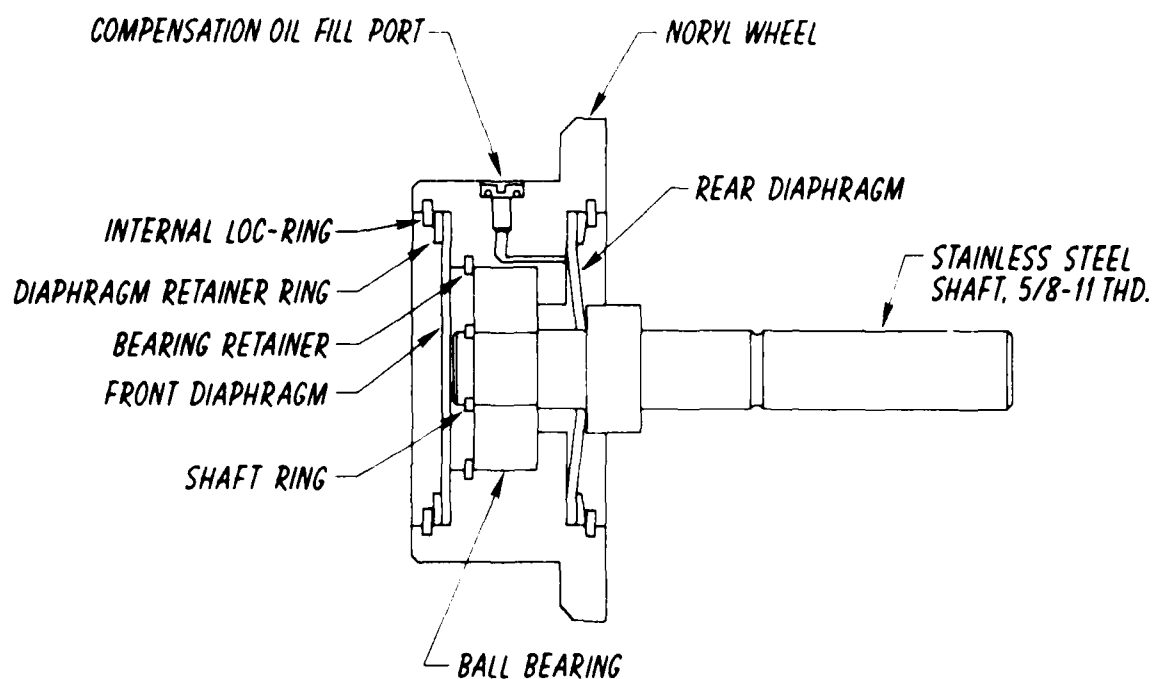


Fig. 86a. Cross-sectional Drawing of a Carousel Trolley Wheel

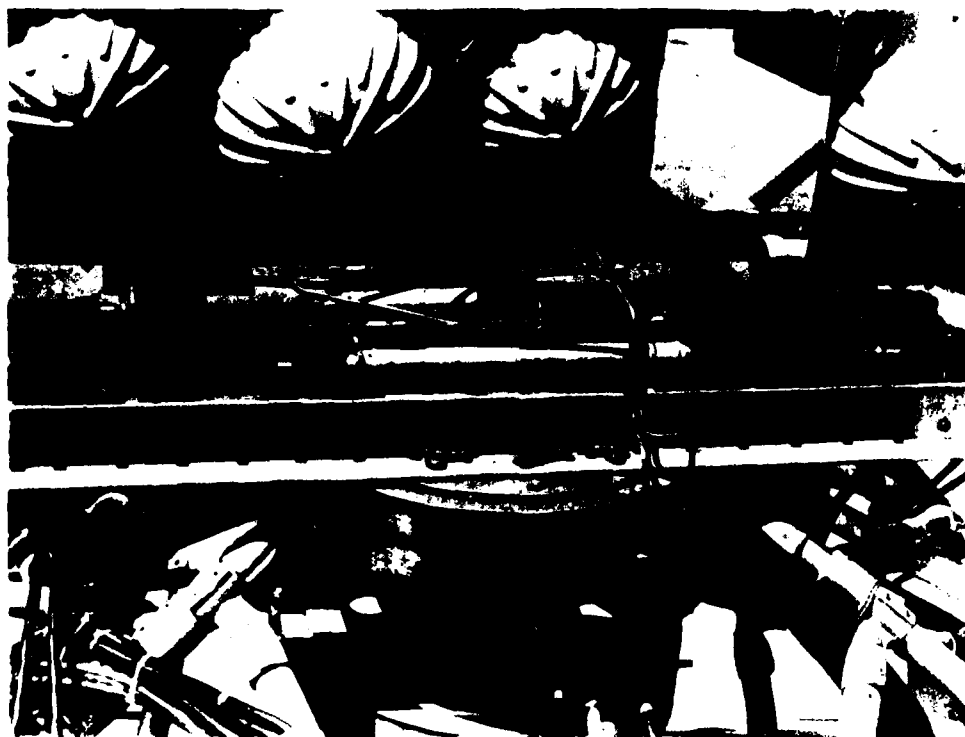


Fig. 87a. Carousel Rotary Drive Mechanism

a plate that is free to pivot about a center swivel pin. The freedom to adjust to the imperfections in the ring would assure that the two wheels are equally sharing the load throughout the full 360 degree rotation. The oil-filled bearing shaft seal that allowed water to enter the assembly will also require a redesign and/or improved method of preventing water intrusion. Figure 86 is a cross-sectional sketch of a typical oil-filled and pressure compensated trolley wheel presently in use.

11.5 Carousel Rotary Drive Mechanism

The power to rotate the carousel is generated through the push-pull arrangement of two dual rod hydraulic cylinder assemblies, double strand roller chains, and mating sprockets as shown in Figure 87. The mechanism was originally designed using single strand chain and sprockets. As additional apparatus was attached to the rotary carousel causing the trolley wheels to become unequally loaded due to ring deformation, the torque required for rotation began to increase far in excess of the breaking strength of the single strand chain. In order to temporarily brute force the carousel into rotary motion, dual chain and sprockets were installed. The mounting frame and drive shaft were not modified to accept the added strain. They are workable in their present configuration, but are considered as marginal.

It is proposed that the cylinder and sprocket mounting rack be re-built to accept the added stress imposed by the increased component and carousel weight. In addition, the stub drive shaft between the driving sprocket and the driven universal joint should be increased in diameter to provide additional strength to prevent shearing in rough sea state recovery. Air/water interface operation has clearly illustrated that severe side loads are imposed on the carousel by surface wave action.

11.6 Hydraulic Fluid Flow Dividers: Test Section Insert System

The two flow dividers are part of the hydraulic circuit that controls the synchronization of the three insert/retract cylinders on the test section. As discussed in Section 6.5, they are considered as marginally acceptable. However, when operated in parallel with the mechanical cable synchronizing system shown in Figure 51, exceptional piston rod tracking is achieved in the three cylinder assemblies.

It is proposed to by-pass the two flow dividers and test the cable system as a single entity. If the three cylinders continue to remain synchronized by the mechanical system and the cable strain does not substantially increase above the present 250 to 275 pound tension range, the dividers will be permanently removed.

11.7 Lead Acid Battery Pack Electrical Disconnects

The breakaway disconnects discussed in Section 3.9.2 and their oil compensation system shown in Figure 32, exhibited an occasional intrusion of sea water during the initial stages of the Sea Duct shallow water test program.

The difficulty was traced to a male pipe thread on the plastic DANCO cable feed-thru fitting. All disconnects were subsequently re-built and pressure tested for leaks using a leak detector bubble solution. There were no indications of leakage during the remaining diver depth deployments.

Leakage was again experienced at the onset of the deep water on site deployment, but investigative efforts failed to uncover the cause. A decision was made to move the oil-filled bladder compensation and water trap shown in the Figure 32 schematic to a physical location that would allow any disconnect

leakage to drain off and collect in the base of the bladder. The bladder, being semi-transparent, would provide an immediate visual indication of water intrusion.

Some thought was also given to the possibility that while the Sea Duct was sitting on deck, the oil was draining out of the disconnect, failing to replenish itself fast enough when the system was initially submerged. To offset this possibility, the anti-syphon check was installed immediately adjacent to the compensation bladder.

Sporadic sea water intrusion was experience throughout the deep water dive series, although it ceased to be of sufficient magnitude to result in electrical shorting within the disconnect.

It is proposed that a thorough investigation be undertaken to review the physical dimensions, O-ring squeeze, and both the disconnect and DANCO feed-thru threads for possible leakage areas.

11.8 Hydrostatic Release Interconnect Tubing Replacement

Several of the 1/8 inch tubes used between the motor driven control valve package (Figure 57) and the shear pin release cones have been mechanically damaged. Replacement of the entire length is not required; a splice fix using a type W125 P/N 15F2211 straight coupling (manufactured by Autoclave Engineering) will be acceptable. A high pressure leakage test will be necessary to assure system integrity. It is also suggested that some re-routing will be necessary in order to provide additional mechanical protection for the exposed tubing.

11.9 Nitrogen Compensation System

The nitrogen system shown in Figure 39 was an experimental device designed to provide gaseous compensation for the recirculating pump and hydraulic pump drive motors. Tests performed at the hydrostatic test facility proved the system's ability to compensate to depths as great as 15,000 feet.

The Sea Duct nitrogen systems have been deployed a total of twelve times, with mixed results. There are two separate and identical nitrogen compensation units on the structure. The first system compensates the hydraulic pump motor, located at the bottom left of the hydraulic package illustrated in Figure 47. The complete package and motor are installed in an oil-filled pressure compensated canister. The nitrogen system used in this application operated flawlessly for the first nine deployments.

At some point after sitting on the fantail of the support vessel for several days, it was noted the motor current drain had increased to a dangerously high level. Disassembly revealed that a small quantity of oil - perhaps as much as 20 c.c. - had seeped into the motor housing and "cooked" itself into a carbonaceous slurry that was shorting out the motor brushes and commutator. The motor was replaced with one that had previously been modified for total oil compensation. The final cruise was successfully carried out with the substitute oil filled motor. No additional testing of the nitrogen system is scheduled at this time.

The second nitrogen system was dedicated to the compensation of the recirculating sea water motors, one of which is illustrated in Figure 26. The initial shallow water deployments in the Buzzards Bay area appeared satisfactory, although a small quantity of moisture in the form of mist was noted on the inside of the plastic tubes used between the nitrogen system and

the motor housing. The system was disassembled and inspected for potential leak points with negative results. Several sets of motors were completely destroyed during the first nine deployments. The destruction was always total and varied widely, occasionally from moderate quantities of salt water intrusion - 3 c.c. and less - to total flooding.

The leakage was extremely evasive - sometimes occurring, while at other times the motors would be perfectly dry. At this point it was decided to revert to a total oil compensated system for the last three deployments. The recirculating sea water pump motors operated satisfactorily throughout the remaining series of Sea Duct operations.

11.10 Vent and Flood Flapper Valve Operation

The vent and flood flapper valves depicted in Figure 19 accomplished their design function during all deployment and recovery phases. There were some indications from the LDV data that at high velocity sea water pumping levels, the suction breaking flapper valves upstream of the pumps were opening and allowing outside sea water to infiltrate the water stream. The two suspected valves were secured in the closed position. This appeared to correct the data deficiency.

It would appear that a wider strip of magnetic plastic tape (used to hold the valves closed) would provide additional holding power and correct the problem.

11.11 Hydraulic Pilot Operated Check Valve Modification

There are nine double pilot operated check valves in the Sea Duct hydraulic system. They lock, or prevent, the hydraulic cylinders and rotary

actuators from moving after the solenoid control valve is closed. Without the check valves, the cylinder would slowly creep as hydraulic fluid gradually weeps past the control valve spool.

The valves (P/N NNAAC-3-10A1) are manufactured by the AA Hydraulic Company. The vendor has notified the Sea Duct project office via their service bulletin CETOP-3(10A1-10B1) that modification kits (P/N 719130) must be installed to prevent possible failure. The upgrade is necessary because the springs could become improperly aligned inside the end caps and could likely lead to added spring stress and failure, causing the check valve to malfunction.

11.12 Recovery tag Line Attachment

In the existing recovery synopsis discussed in Section 10.0 entitled **Sea Duct Deployment and Recovery Procedures**, the structure must be brought approximately three quarters of the way out of the water before the Zodiac crew can secure the necessary tag lines. At this point the structure, fibreglass duct work, glass viewports and the rotary drive mechanism are extremely susceptible to wave action damage. If everything goes well, it requires approximately five minutes to secure the handling lines.

One past operation that submerged the Sea Duct test section some 3 to 4 feet under water while a test was performed, actually resulted in the top viewport being smashed by wave action. Referring to the frontispiece, the tag lines are presently secured to the lower section of the vertical legs, just above the angle formed by the 30 degree tubular cross member.

It is not suggested that the point of attachment be changed, but that

short lengths of the tag line become a permanent part of the Sea Duct. This can be done by securing one end of the tag line at its normal location, and running the free end up the vertical leg where it can be held in position with a bungee cord. With the modified procedure, the Zodiac crew can secure the block and tackle line without having the Sea Duct at its most vulnerable level, mainly half submerged at the water/air interface.

11.13 Sea Duct Lift Bridle

The lift bridle is fabricated from 3/8 inch diameter, 6 X 19 galvanized steel cable with an outer protective jacket of polyethylene plastic. The average breaking strength of a single cable is 10,000 pounds. The end terminations are forged steel swage sockets.

The bridle consists of six individual cables that are secured at the base of each of the six 4-inch tubular legs on the exoskeleton. Figure 88 is a typical cable swage fitting secured to the fish plate on the structure.

The bridle has been deployed a minimum of twelve times and has been completely flooded by the "wicking" of sea water along the cable strands. From a safety standpoint, it is suggested that a new bridle be constructed and installed prior to follow-on deployments. As an additional precaution, the tie-down bolts used to secure the cable fish plates to the Sea Duct structure should be replaced.

As a point of interest, Figure 88 provides a clear view of the battery pack roll-out pivot that mates with a round bar secured to the bottom of each battery canister mounting frame. When the emergency release is activated,

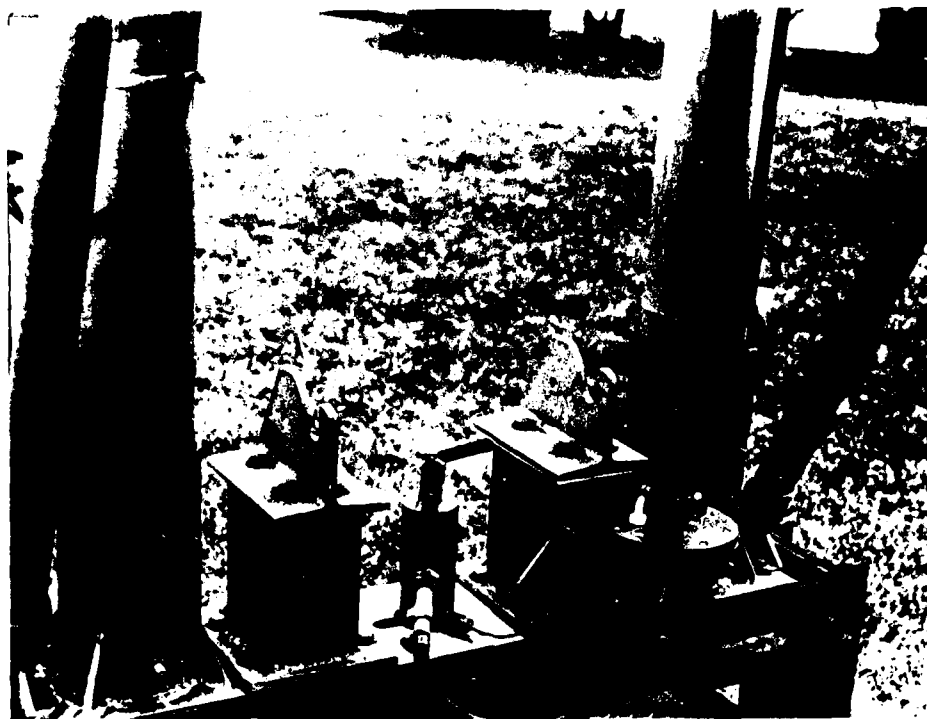


Fig. 88a. Lift Bridle Swage Fitting and Attachment Boss

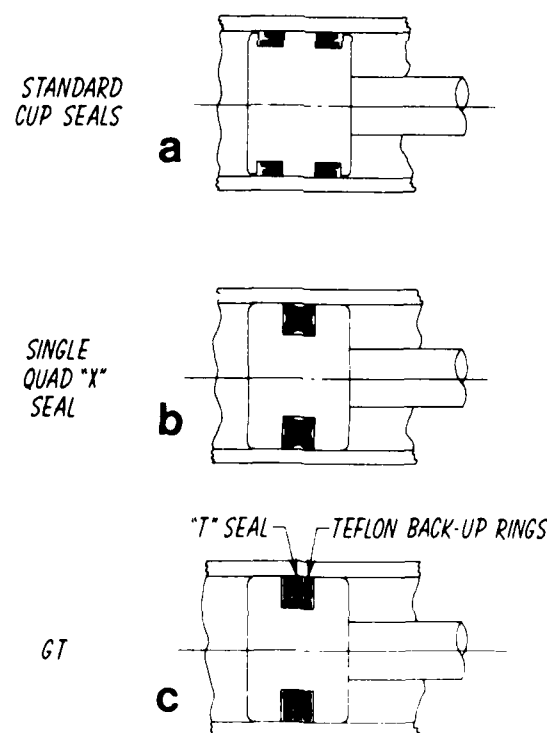


Fig. 89a-c. Hydraulic Cylinder Piston Seal Modification

the batteries rotate around the off-center pivot until they fall free of the Sea Duct structure.

11.14 Hydraulic Cylinder Piston Seal Modifications

All Sea Duct hydraulic piston assemblies are commercial off-the-shelf components. Referring to Figure 89a, the dual opposing cup seal design is a typical configuration for double acting cylinders. The Sea Duct hydraulic system is pressure balanced by allowing external ambient sea water pressure to be applied to the hydraulic fluid on both sides of the piston. Pressure as great as 6500 PSI can be experienced on both cup seals.

As illustrated in the sketch and except for minor seal weepage, there is a low pressure "dry" void between the seals. When pressure in excess of the 1500 PSI component design pressure is applied, one or perhaps both seals will rupture inwardly. To correct this problem, new pistons, each with a single seal groove, were machined and installed. Depending on the type of usage, either of the two seals illustrated in both Figures 89b and 89c will correct the pressure unbalance condition of the original dual seal.

It is important that all replacement hardware or new hydraulic components that are added to the Sea Duct be reviewed or disassembled for inspection to assure low pressure voids do not exist.

11.15 Rotary Position Transmitter Location Modification

The heading, or angular position, of the test section in relation to magnetic north is determined by a rotary position transmitter that is coupled to the hydraulic drive chain. In its present location, the clearance between its electrical disconnect cable and sections of the fixed exoskeleton is

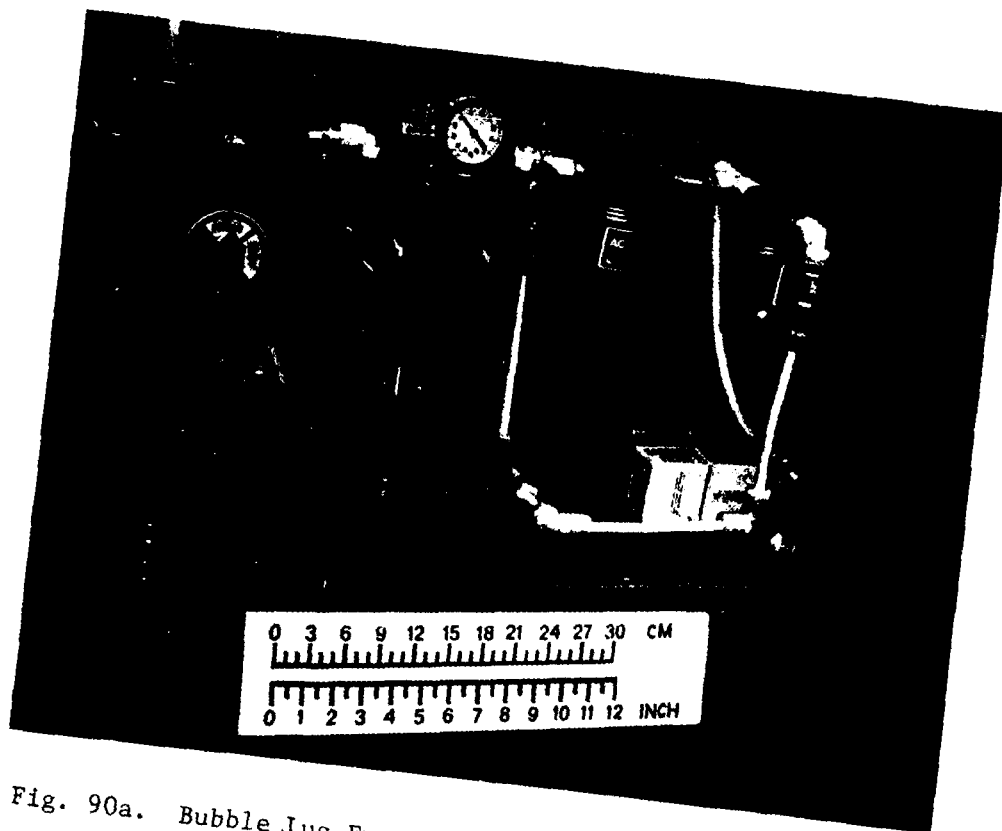


Fig. 90a. Bubble Jug Evacuation and Back-Fill System

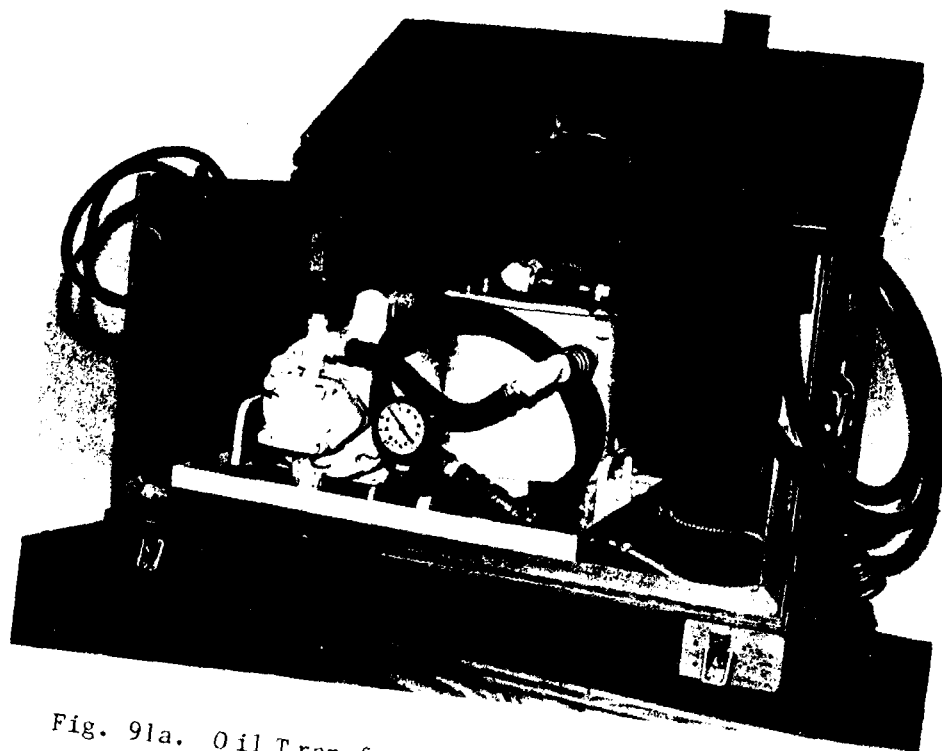


Fig. 91a. Oil Transfer and Filtration System

sufficiently close to result in mechanical interference. Several electrical connectors were inadvertently damaged during dockside tests.

It is proposed that the rotary position transmitter be relocated to assure the electrical cable will have sufficient clearance to prevent future problems. In addition to the existing mechanical difficulty, the housing of the magnetic coupling is positioned in such a way that it traps sea water and will not self-drain. The relocation design modification must include the self-draining capability to eliminate the generation of salt water gurly that forms in the cavity of the aluminum cup.

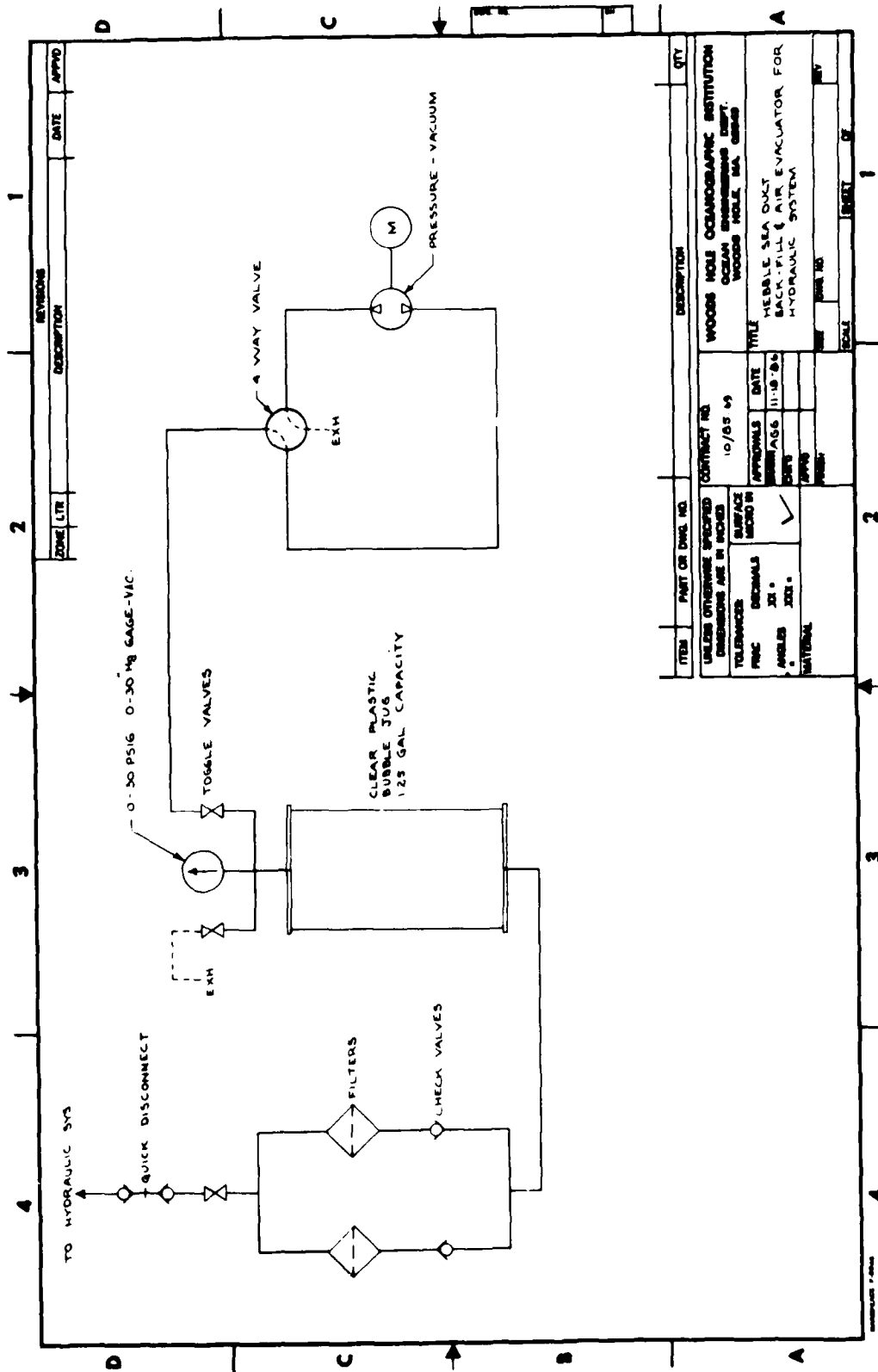
12.0 Sea Duct Support Equipment

12.1 Battery Charger

The lead acid raw power battery packs are recharged by a battery charger (Model A12B-100-24V-A1) manufactured by the LaMarche Manufacturing Company. The input primary transformer winding requires a 120 volt, single phase 50 ampere 50/60 cycle power source. An ancillary multi-tap transformer has been included as part of the input circuit. It provides the interface between the ships 480 volt, 3 phase supply and the charger primary winding. The use of the shipboard 480 power source substantially reduces the amperes required when using the 120 volt supply.

12.2 Hydraulic System Bubble Jug

The apparatus illustrated in Figure 90 is used to evacuate entrapped air from the hydraulic system, and to pressure back-fill the accumulators. Referring to Figure 92, Bubble Jug Schematic, the system uses a combination vacuum/pressure pump that will either evacuate fluid and entrapped air from a high



A-128

Fig. 92a. Bubble Jug Schematic.

point in the Sea Duct system, or, by repositioning the control valves, pressure-fill the hydraulic circuit. Automotive fuel filters and check valves continuously filter the hydraulic fluid regardless of the pumping mode. The clear plastic container acts as a fluid reservoir and as a sight gauge indicator that all entrapped gas has been expelled.

12.3 Oil Transfer and Filtration System

The filter system illustrated in Figure 91 is a dual service unit. It provides the means of transferring a high volume of compensation oil in to or out of the lead acid battery packs, while simultaneously filtering and removing any acid and/or water suspended in the fluid.

The battery canisters are static systems and for the most part, if sea water enters the device, it does not readily emulsify with the compensation oil. It will eventually settle out as droplets at the systems low point, or water drain sump. The battery electrolyte however, does enter into suspension and if not removed or neutralized, will eventually result in reduced dielectric properties of the compensation fluid. The combination of sulfuric acid, water, and deteriorating dielectric qualities will eventually damage the battery and aluminum mounting racks.

The oil transfer/filter system is a Model OF-1000, manufactured by Leybold-Heraeus Vacuum Products of Export, PA. The hydrophilic filter element for water and acid absorption is P/N 898506. In the event of inadvertent flooding of the hydraulic system, the pump and hydrophilic element can also be used to recirculate, flush and filter the MIL-H-5606 fluid in the system. To assure adequate flushing and water removal, it is suggested that

the hydraulic pump be operated and all valves and cylinders be cycled several times to provide a complete turnover of fluid within the system.

12.4 High Pressure Nitrogen Booster Pump

The high pressure accumulator illustrated in Figure 39 is charged with dry nitrogen to a 3300 PSI pressure. Normal nitrogen tank pressure as received from the vendor is 2200 to 2500 PSI. To boost the charge pressure to 3300, a Haskel Model AA-30-C pneumatic piston booster pump is used. It operates from a compressed air source, with a minimum pressure of 165 PSI.

Sea Duct Electronics

1.0 Introduction

The design of the Sea Duct microprocessor, control electronics and electrical system began in 1983. Many people over a four year period have been involved in design, construction and testing of the system.

The control system can be divided into two main sub-sections - hardware and software. Although they interact in many ways, they will be discussed separately.

All hardware is controlled by software drivers which are called in a pre-defined sequence. A higher program level contains the sequencer code which is written in a high level language designed specifically for the Sea Duct. These high level sequence commands are easy to understand, and their order may be easily modified to meet the requirements of a specific experiment. During testing and shallow water deployment, the instrument may be controlled by individual commands from a video terminal or personal computer. A manual control box may also be used when the instrument is not submerged.



2.0 Sea Duct Electronics Hardware

The Sea Duct electronics system is relatively easy to understand when it is broken down into its nineteen subsystems. In some cases these subsystems control several system functions. Most control only one, while one controls more than two dozen. Figure 1b presents an overall view of the system.

A large number of hardwired control lines require a large number of electrical penetrators or connections through the end cap of the controller housing. Specifics of the CPU housing mechanical design may be seen in Figures 52a and 53a. The end cap itself has 100 single pin penetrators made by the Sinclair Manufacturing Company (P/N TB-THSW605SS). Schematic SD-B032 in Appendix I gives details of the end cap and penetrator design. Attached to the end cap is an oil-filled PVC housing with the actual underwater connectors mounted radially around the outside of the housing. The underwater (U/W) cables may be removed to isolate the controller from the instrument. Brantner Sea-Con XSG-8-BCL and XSK-4-BCL are the most common multiple pin underwater connectors used here and throughout the instrument.

The electrical wiring outside the CPU housing is logically split at the rotation point. Part of the system is mounted on the rotating portion of the instrument; part is mounted on fixed structure, such as the tripod legs. The dividing line is usually shown in the drawings. A block diagram of this main wiring harness is given in Dwg. SD-B031 (Appendix I). The majority of the wiring is done with single, four, and eight wire neoprene (Type SO or SOW) cables.

Where possible (almost every instance) at least one end of a cable is terminated inside an oil-filled junction box. These boxes offer the advantage



Fig. 2b. IDV and Carriage Detail



Fig. 3b. Transmissometer Position in Recirculating Flume

of low cost and easy access to connections. Oil forced into the cables from the boxes minimizes cable flexing failures caused by the high pressure, low temperature environment. After each deployment the boxes must be checked for leaks, and small amounts of salt water drained. Oil reservoirs must be full before each deployment. Danco bulkhead fittings M19622/1.004 and M/19622/1.005) are used to terminate the cable at the housings.

Shielded twisted pair is needed for the transmissometer analog signals and SAIL communication. In this case, the wire consists of two separately shielded twisted pairs in a PVC jacket (Belden 8723). This wire is run through oil-filled Tygon tubing with push-in tubing connectors. The same tubing is used for the control cable in shallow water (<75 ft.) deployments.

Five types of oil-filled connector housings are used. A rectangular PVC box which can accept up to eight Danco or Brantner connectors is called a "Box" and has a letter identifier (e.g. Box B). One example, Box G, can be seen in Figure 2b. A smaller, round box has a pie-shaped bottom and is referred to as a "pie box" (e.g. Pie Box 3). Three small cylindrical boxes are used to transfer wire in tubing to underwater cable. These are called "pipe boxes", (e.g. Pipe Box 1, 2, or 3). Figures 3b and 4b show the pipe box used with the transmissometer system. A fourth box is the large junction box mounted near the main hydraulic system housing. Figure 5b shows the main junction box with its cover removed. Finally, three quick disconnect connectors with aluminum housings as described in the mechanical section, are used to connect the main system batteries to the instrument.

2.1 Hydraulic Interface

As detailed in the Sea Duct mechanical description, mechanical motions such as flume rotation and insertion are powered by a hydraulic system.



Fig. 4b. "Pipe Box"
Detail

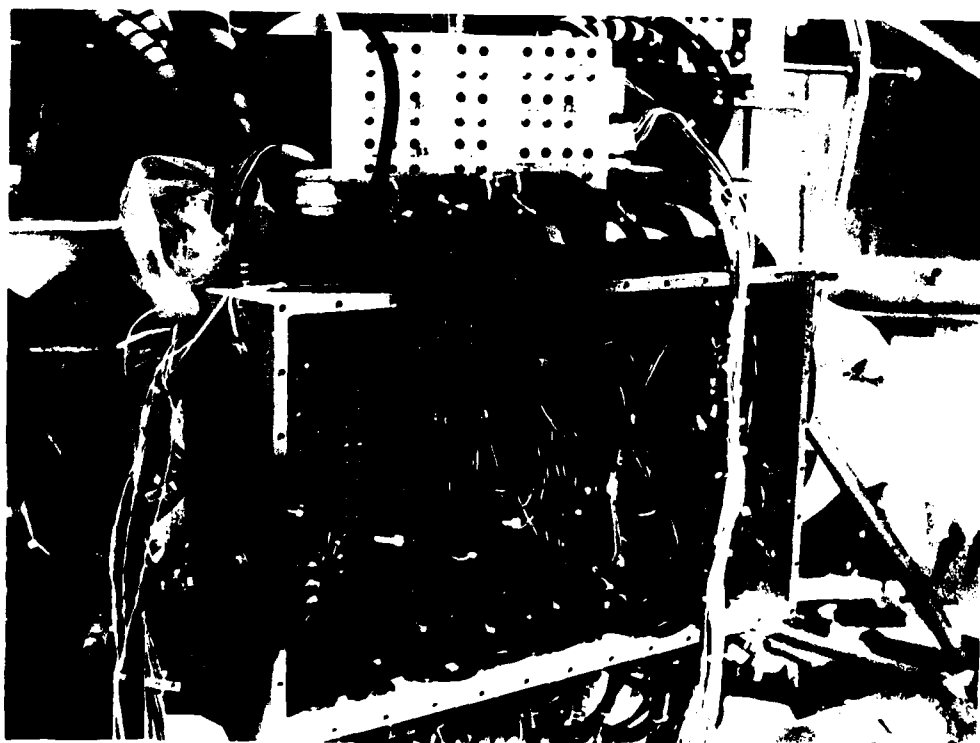


Fig. 5b. Main Junction Box

Electrically controlled valves direct the flow in the system. These valves draw relatively large electrical currents. The electric hydraulic pump motor draws approximately 15 amps. In 1983, high current field effect switches were not considered reliable enough, so relays were used to switch the high currents required by the pump motor and hydraulic valves. Latching relays are used for the valves, and a high current relay controlled by a latching relay is used for the pump motor. The relays are housed in PVC oil-filled cylinders referred to as "cans" (e.g. Can 3). Figures 42a-45a contain details of the relay pods.

All relay control lines and outputs have been routed through a central junction box. Almost all control lines from the CPU pass through this main junction. This box may be drained and opened when required for trouble shooting or modifying the instrument.

Drawings SD-C002 and SC-D001 contain the relay box schematics and the layout of the main junction box. Figure 5b is a picture of the wiring inside the box.

2.2 Power Supply

Three distinct battery systems supply power to the instrument. These systems are shown in Dwg. SD-B009. Particular attention has been paid to avoiding ground loops and high impedance grounds. The common ground point for systems referenced to the system and EHRS battery grounds is on the bus bar (TB-08-1) located in the main junction box. The only common point between the system and microprocessor supplies is located in the CPU housing on the output driver board (see Dwg. SD-B016). Pressure housings have been electrically isolated from the Sea Duct frame and the battery grounds. This has proven effective in keeping electrolytic corrosion to a minimum.

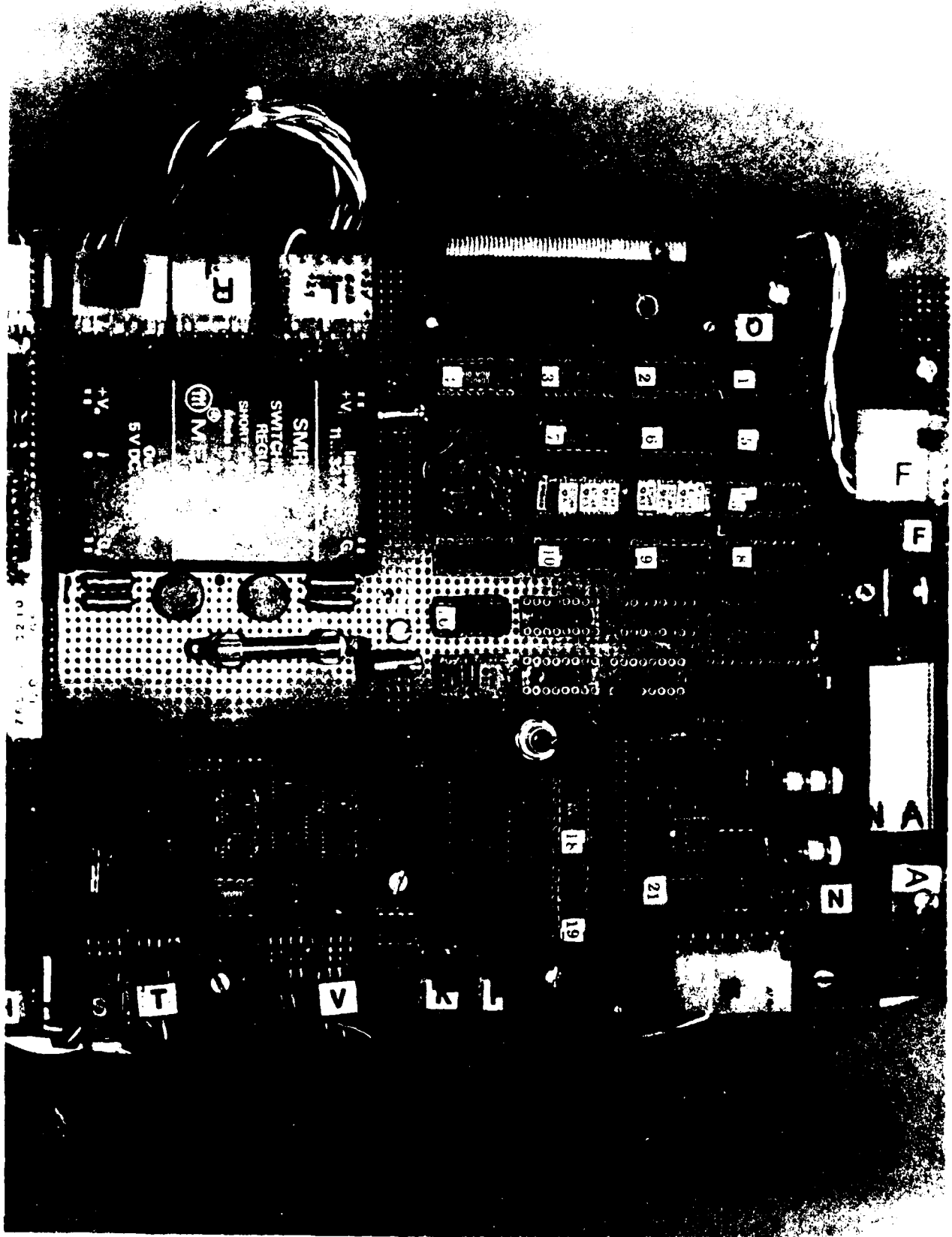


Fig. 6b. Buffer Board and Microprocessor Power Supply

2.3 Microprocessor Power

The microprocessor power source is a 24 V Lithium battery (Electro-Chem 3PD61 with a 2 amp fuse). As with all Lithium batteries, proper safety procedures as provided by the manufacturer should be followed. A copy of the sheet can be found in Appendix G.

The microprocessor battery is in the battery housing on leg two of the tripod. Four single pin Mecca U/W connectors mate with a group of four single wires which go to the microprocessor via Pie Box 4 and Connector U/W-B on the CPU housing (Dwg. SD-B009). When "shore power" is used, a power supply may be connected to the microprocessor system via two of these wires.

Inside the CPU housing, the microprocessor battery is connected to the Output Driver board (Dwgs. SD-B016,017) and the Buffer board (Dwg. SD-B012-15). A special cable for CPU bench testing exists and may be inserted between connector G and the cable normally inserted in G. A current limited power supply (~ 750 mA at ~ 20 -24 V) is required.

The power supply on the Buffer board (Stevens-Arnold, WF12 S05-1000 or Melcher SMRF 51 6i) supplies the regulated +5 V DC required by the microprocessor system (Fig. 6b). Raw +24 V is supplied to the Sea Data recorder via a 6.8V, 10W zener diode for the motor drive supply. Raw +24 V is also supplied to five high current (~ 1.5 A typical) pulse drivers and to the five drivers on the Output Driver board.

2.4 System Power

Power for hydraulic system and the flume pumps is provided by three 24V battery packs consisting of four 158 Ahr. (at an 8 hr rate), 6 V lead acid batteries (Exide EV106), Reference 13. Each battery pack is connected to the

instrument through a quick disconnect connector and Junction Box A. Box A has Brantner U/W connectors that are used to charge the system battery (Drawing SD-B009). Relays in Relay Can 1 are used to switch each of the three system batteries in or out of the system. The system battery relays are controlled by the microprocessor and are powered by the microprocessor battery. The manual control box can be used to control these relays; however, a separate "jump-start" battery is required. Batteries switched into the system are isolated with Schottky diodes.

Box B, mounted near the flume pump controller has a two-pin Brantner U/W Connector (XSG-68-BCL) that may be used as an input for "shore power". Power may be applied with or without the system batteries connected to the system. An isolation diode in series between the power supply and Box B must be supplied. The supply must be capable of supplying approximately 50 Amp at 24 to 30 volts. A power cable of sufficient capacity to reach Sea Duct without significant voltage loss is required. At the present time, a 60V, 40A supply and a 75 foot, 10 AWG cable with a series diode (Motorola MBR-7545 [75A, 45V]) near the power supply is used.

2.5 Emergency Hydrostatic Release System Power

The Emergency Hydrostatic Release System (EHRS) uses a separate Lithium battery located in the same housing as the microprocessor battery. The battery is the same as the microprocessor battery (Electro-Chem Model 3PD61), but must be modified before use.

The EHRS battery is modified by replacing the fuse supplied by Electro-Chem with a 3.5 amp fast blow fuse (Littlefuse 255.03.5). Heat shrink tubing should be replaced to avoid any possibility of accidental shorting. This

modification is made with Electro-Chem's verbal approval. Originally a 12 V battery with a 3 amp fuse was used (Electro-Chem 3PD60), but it could not run the EHRS valve motors at cold temperatures.

Connections from the battery housing to the instrument are made with two single pin Mecca connectors. A laboratory power supply may be used for testing and can be connected to the instrument at this point (Dwg. SD-B009).

2.6 Central Processing Unit System

The heart of the Sea Duct microcontroller is the Central Processing Unit (CPU) board developed by Ed Mellinger and Al Bradley for use in RELAYS, Sea Duct and other projects. Use in other projects substantially reduced design and development costs. Drawing SD-C001 in Appendix I is the schematic of the board. Figure 7b is a picture of the board layout. Figures 8b and 13b show the board mounted on the CPU chassis. General specifications include:

- RCA 1802/1805/1806 CPU
- 3 UARIS (RCA 1854) with independent Baud rates to 19.2 K Baud
- SAIL (IEEE 997) interface wired to UART #1
- RCA 1851 Parallel I/O
- Vectored interrupt control (RCA 1877)
- 64 K x 8 bit memory (6166 Ram or 2716 Prom)
- On board Prom programmer (external programming supply)
- Memory Page write protect - software controlled
- Buffered Memory and Address Busses
- I/O Group Select allows 48 I/O Ports
- CPU Bus available on connector
- Processor Halt circuitry for low power mode
- Direct Memory Access I/O
- Board size - 7.5" X 19"

The RCA CD1806ACE microprocessor is used on the Sea Duct CPU board. The crystal frequency is 1.2288 MHz. Unused portions of the board usually do not require IC's for proper operation of the remaining functions. Unused functions in the Sea Duct system are the 1851 I/O, UART 3, and a large portion of the memory.

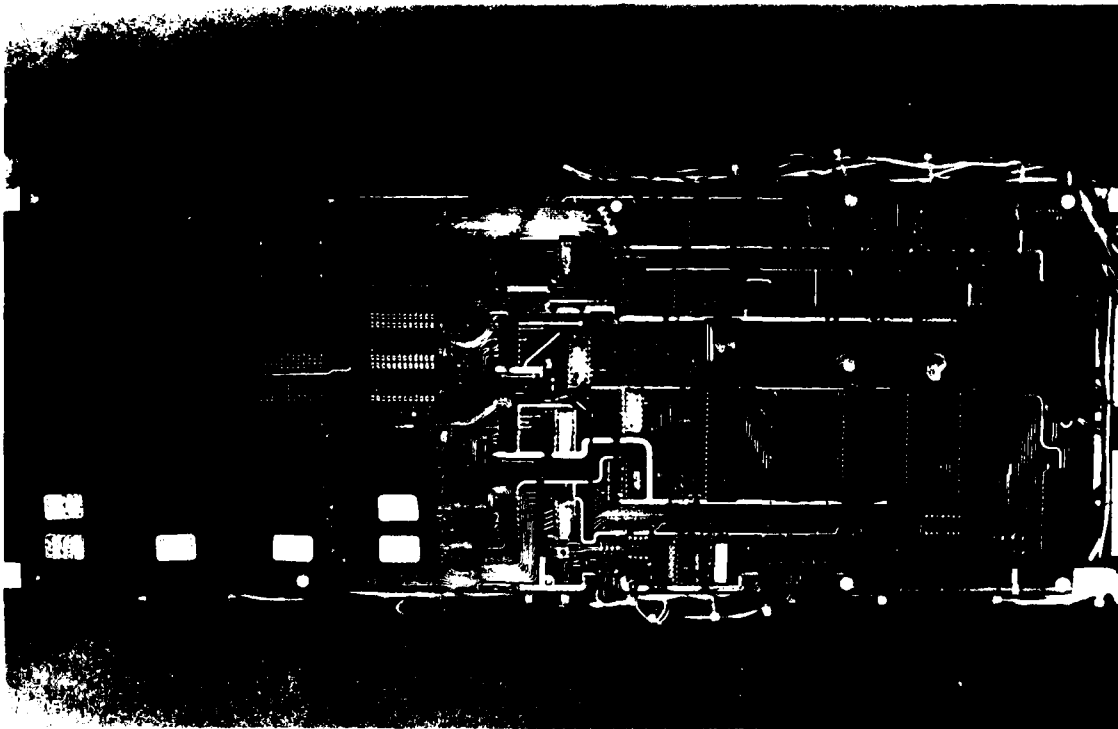


Fig. 7b. CPU Board

The CPU board is designed to use 2716 or 27C16 EPROMs, 6116 RAMs, and Mostek MK48Z02B zero power (battery backed) RAMs. Intel D2716 (450 nsec. access time) PROMs and Hatachi HM6116-4 RAMs have proven to be more reliable. CMOS EPROMs (27C16s) are not required and seem to have caused occasional problems. RAM and EPROM may be used as required in any memory socket. Each socket or memory chip represents 800 H words or 2K x 8 bit memory locations. A jumper beside each socket must be changed when switching between read/write and write-only memory. On occasion, the memory write protect circuitry may be disabled by removing IC 10 and installing a jumper between pins 10 and 22 of the socket.

Power is supplied to the board via J2 from the regulated 5 V supply on the Buffer Board (SD-B012). The CPU board's primary connection with the Sea

Duct system is via J1. Signals available include all pins of the 1806 CPU with the exception of the XTAL and CLK. These lines are buffered on the Buffer board before connecting with the rest of the Sea Duct system.

The 20 mA. Serial ASCII Instrumentation Loop (SAIL) protocol is used to communicate with the instrument (Ref. 14,30). UART No. 1 is used. The control SAIL is available at end cap connector U/W-C which connects via I/O-C to J4, the CPU SAIL connector. Communications with the LDV (presently disconnected) and the flume pump controller use a second SAIL loop and UART No. 2. J2 gives logic level access to all three UARTS.

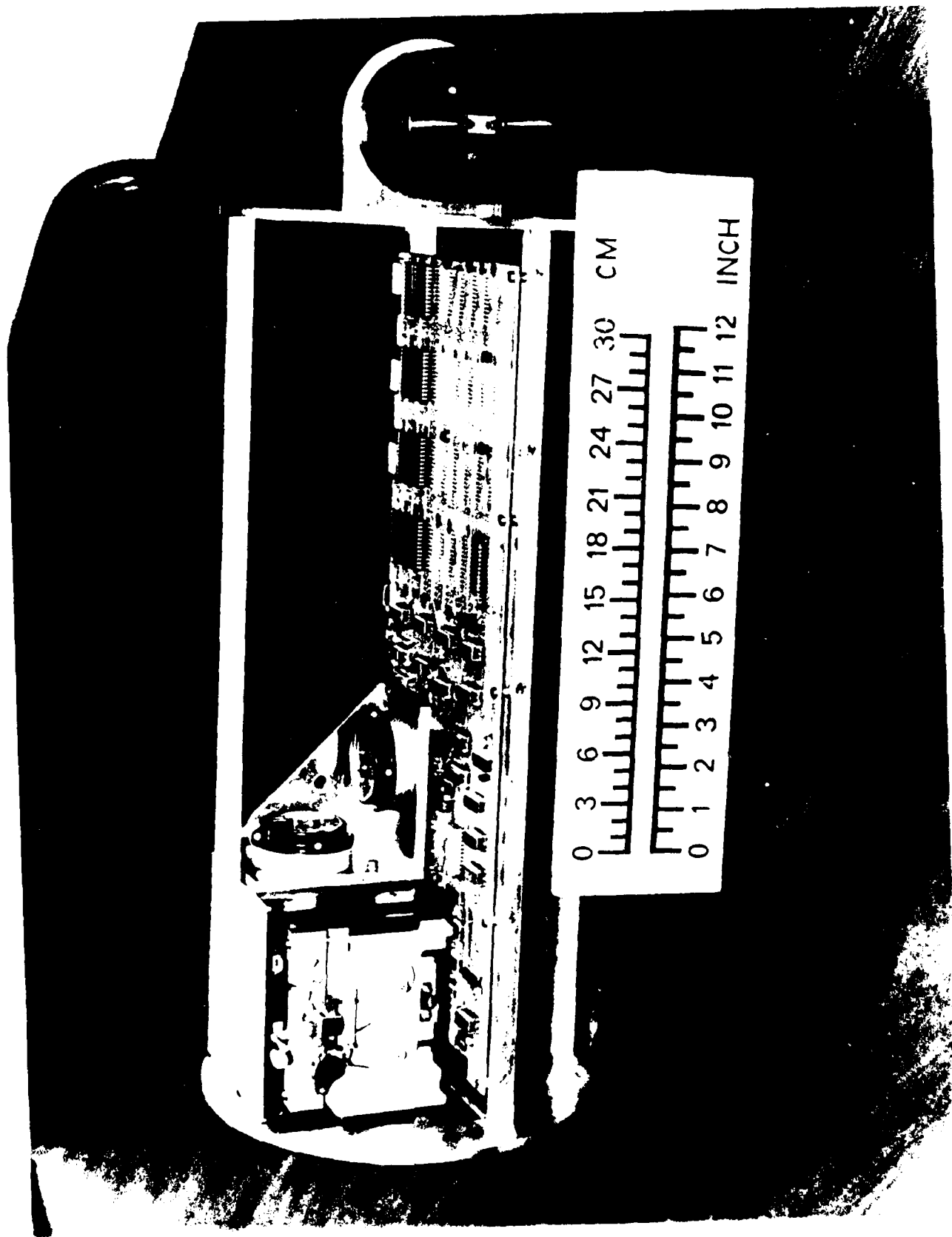
2.7 Buffer Board

The Buffer is the primary interface between the CPU and the Sea Duct system. It contains several functions: CPU signal buffers, logic analyzer interface, pulse drivers, serial communications, CPU reset, and 5 volt supply. Circuitry for an old design circulation pump control exists, but is not used. Drawings SD-B012 thru -15 contain the schematics and board layout. A picture of the board is shown in Figure 6b.

Buffers are used on each output signal of the CPU to reduce the effects of line capacitance. Experience has shown that without buffering, the RCA 1800 series can only drive about 2.5 feet of ribbon cable. Control lines and the I/O buss are buffered.

A minimum testing configuration consists of the CPU and buffer boards connected via connectors J2 and Q. Power can be supplied to the Power Connector on the buffer board or U/W-B on the end cap. The SAIL control loop can be connected to connector T or to U/W-C on the end cap. A logic analyzer interface is provided at connector P. Drawings SD-B028 thru -30 give the

Fig. 8b. CPU Chassis with CPU Board, Recorder, Pendulums and Compass.
B-14



details of interfacing with Hewlett-Packard 1630D and 1610B logic analyzers. Dedicated analyzer interface boxes were built for system testing.

Eight pulse drivers on the buffer board provide high current control pulses for the compass, system battery relays, LDV reset, camera actuate, and acoustic transponder transmit. I/O select decoding uses wirewrap jumpers to allow easy modification. The pulse lengths are controlled by one shots which drive a Sprague 2804A octal output driver. Drawing SD-B006 lists the function, I/O decoding, and pulse widths. The system battery relays, compass and a spare driver have high current outputs sourced from the microprocessor battery. Low level pull down pulses ('switch closures') are used for the camera, pinger, and LDV reset. Note that the LDV reset and the camera actuate are electrically isolated from the Sea Duct system. Separate power sources in these systems require use of optical drivers to protect the buffer board from accidental reverse polarity connection. The transponder ground is connected to the microprocessor ground at connector M-1.

Drawing SD-B013 gives the details of the power-on reset and SAIL loop 2 circuitry. The SAIL control loop (loop 1) passes thru this board. Drawing SD-B010 shows how these are connected to the outside world. The microprocessor battery is the source for SAIL loop 2's 20 mA. supply. Loop 2 power is controlled on the output driver board. Power consumption is reduced by keeping loop 2 off when not in use.

The power-on reset circuitry allows the Sea Duct CPU to be reset on power-up, with the reset switch on the CPU board, or by an external switch which can be used in conjunction with the SAIL control loop (loop 1).

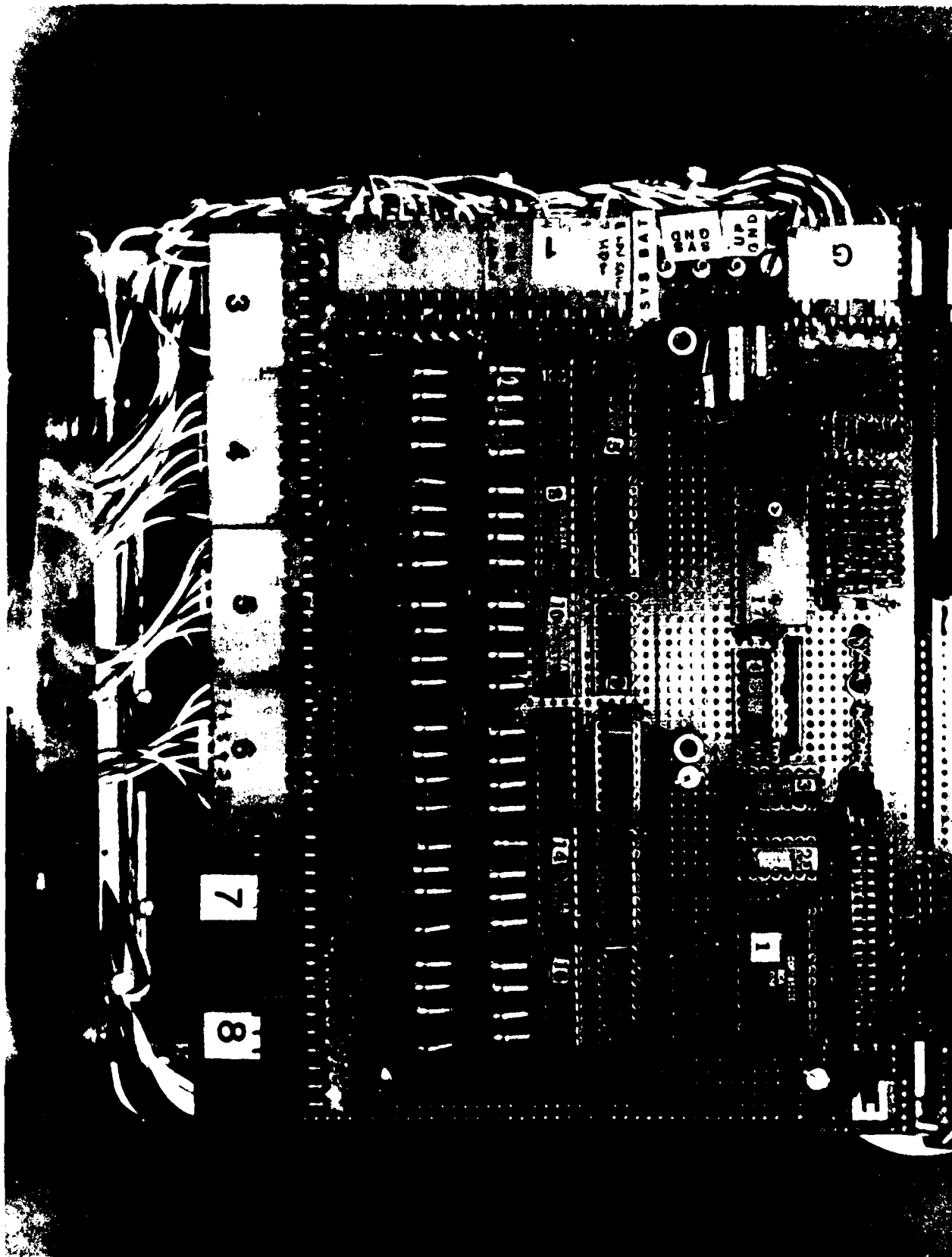


Fig. 9b. Output Driver Board

2.8 Output Drivers

High current (2 amp minimum, 24 V) drivers on the output board (Dwg. SD-B016, 017) provide control signals to the latching relays in the hydraulic system as well as power for the XYZ opto interrupters and sense switches. The system battery is the power source for these output drivers. Six additional drivers (0-5) power SAIL loop 2, the heading indicator, and the transmissometer using the microprocessor battery as a source. The grounds of the microprocessor and system batteries are tied together on this board. The output driver board is pictured in Figure 9b.

Wire wrap jumpers set to Group 2-I/07 select the I/O decoding for this board. Hardware decode and latch functions can control up to 48 drivers. Drawing SD-B005 presents the decoding scheme used to control the drivers. Software routines allow the drivers to supply continuous levels or pulses.

Sense lines with input protection are used to monitor the status of individual relay cans. One line is provided for each can. This limited monitor can show that all functions in the relay pod are off, or that one or more functions are on.

2.9 Manual Control

The Sea Duct controller uses pulses from the output driver board to operate latching relays which control the mechanical system. The transistor drivers do not actively ground the input to the latching relays. It is possible to control the latching relays manually, sending them pulses.

A manual control box also is available for testing and control when the instrument is not in the water. This box, pictured in Figure 10b, may be used

with or without the CPU system connected. The manual control connects to the system at the top of the main junction box using connectors JB1 and JB2. JB2 is used only when control of the hydrostatic release system is needed. Figure 5b shows JB1 and JB2 at the top left corner of the main junction box. JB1 is a 50 pin circular connector that is covered and oil-filled during deployment. JB2 is a four pin Brantner XSG-4-BCL connector that is capped with a RMG-4-FSD dummy connector during deployment.

Controls for the three system battery relays are provided. A separate "jump start" battery must be used for manual control of these three relays. The jump start battery connector is part of the manual control cable. The jump start can be any 12-24V DC source capable of supplying about two amps. Drawing SD-B027 is the schematic for the manual control box.

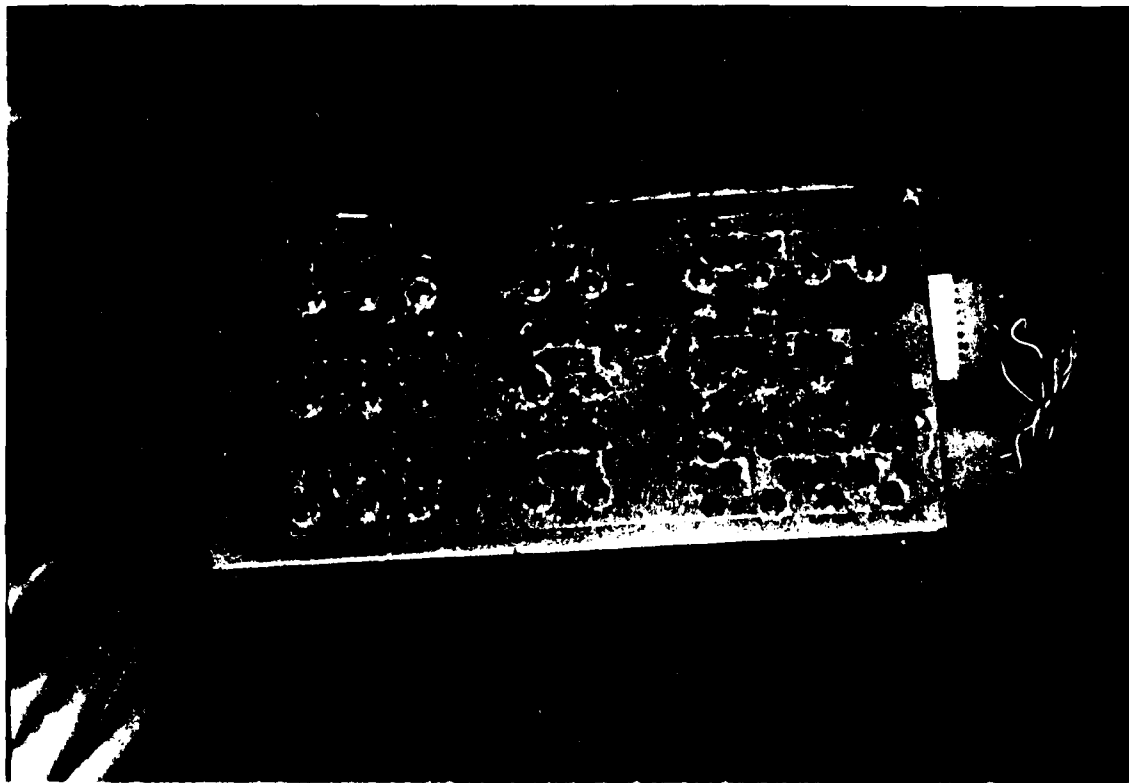


Fig. 10b. Manual Control Box

LEDs on the control box monitor all of the mechanical functions removing the limited monitoring ambiguity of the output driver board.

It is suggested that the manual control be in place anytime the instrument is powered up and people are working in or near parts that can move. It is much easier to stop things with the push of a button than typing a control sequence to the microprocessor controller.

Caution is advised when using the manual control while the microprocessor sequencer is controlling the instrument. For example, consider the case where the microprocessor is controlling the motion of the X,Y,Z carriage. Typically, the microprocessor turns on the hydraulic pump, starts the traverse, waits until the traverse is done, stops the traverse, and finally stops the hydraulic pump. For our example, during the traverse, the pump and traverse are manually turned off. The microprocessor will wait until the time-out for the traverse occurs, and then send pulses to close the traverse valve and stop the pump. Because they have just been manually stopped, they will actually be turned on again by the microprocessor controller. Thus, it is important to be aware of what the controller is doing when using the manual controls.

2.10 Transmissometer

The Sea Duct transmissometer is manufactured by Sea Tech, Inc. The optical path length is 25 cm. The transmissometer is mounted near the outlet end of the test section just before the 6-inch round pipe as shown in Figure 3b. The transmissometer in use at the present time is S/N 35D. Specific operation and calibration details can be found in the transmissometer manual.

Connections between the transmissometer and the microprocessor controller are shown in Dwg. SD-B010. The wire used consists of two separately shielded

twisted pairs in a common PVC jacket (Belden 8723). This is encased in oil-filled tygon tubing as shown in Figs. 3b and 4b. One twisted pair delivers power supplied by the microprocessor battery. The other pair returns the analog output to the CPU. Transmissometer power may be turned off by the sequencer when not needed.

2.11 Analog to Digital (A/D) System

Analog sensor outputs are converted to a 12 bit digital format on the interface board (Fig. 11b). Eight analog signals are sequentially channeled to the analog-to-digital converter (A/D), using a sixteen channel multiplexer (8 spare inputs exist). Drawings SD-B018 and SD-B021 give the details of this system. Control codes for the A/D and multiplexer are detailed in Dwg. SD-B006. A low power mode may be used when the A/D is not needed. In the Sea Duct system, one analog channel is measured every 50 milliseconds.

A stable voltage converter supplies the $\pm 5V$ required by the A/D. Tests show the converter to be stable within 1 LSB over the expected operating temperature range of the instrument. The A/D ground, reference, and full scale voltages are measured and recorded in case drift occurs. The A/D ground output is elevated and the full scale output is lowered so that drift cannot force readings beyond the allowed output range. Analog inputs to the A/D enter the interface board through connectors B and C, where grounds are available for signal shielding.

The system and microprocessor battery voltages are measured through a precision voltage divider (30 V. = full scale). The battery voltages are recorded using eight bits.

To record the tilt of the system, two Humphrey Model PL7-0601-1 pendulums are used. These are labeled pitch and roll. Pitch is along the axis of

the CPU housing with output increasing as the U/W connector end is lowered. Roll is perpendicular to the CPU housing axis and increases as the connector end cap turns counterclockwise as one faces the end cap. An A/D conversion program for the Hewlett-Packard 16C calculator can be found in Appendix M.

2.12 Compass

A Digicourse Model 218 compass with 1.4 degree (8 bit) resolution is used to record the orientation of the tripod with respect to magnetic north. Compass information, together with flume heading is used to orient the flume in the proper direction. The lubber line is on the axis of the CPU housing. The compass reads north when the CPU connector end cap faces north.

Details on the compass can be found in the Digicourse Manual. Drawings SD-B019 and SD-B021 give the details of the compass interface which is located on the interface board. Figure 11b shows this board and a side view of the compass. The compass can also be seen in Figure 8b. The compass is mounted at the end of the CPU chassis away from high current drivers which are located near the end cap.

The microprocessor system reads the compass every ten seconds. A 10 msec., 24 volt pulse from the buffer board powers the compass. Five milliseconds after the start of this pulse, the data is latched and converted from gray code to binary format. An I/O port latches the binary data 100 microseconds after the conversion starts. The I/O port is read on the next interrupt cycle which occurs approximately 25 msec. later.

2.13 Heading Indicator

The orientation of the flume with respect to the tripod is sensed with a Litton Model 76 Rotation Encoder. Mounted in a separate pressure housing

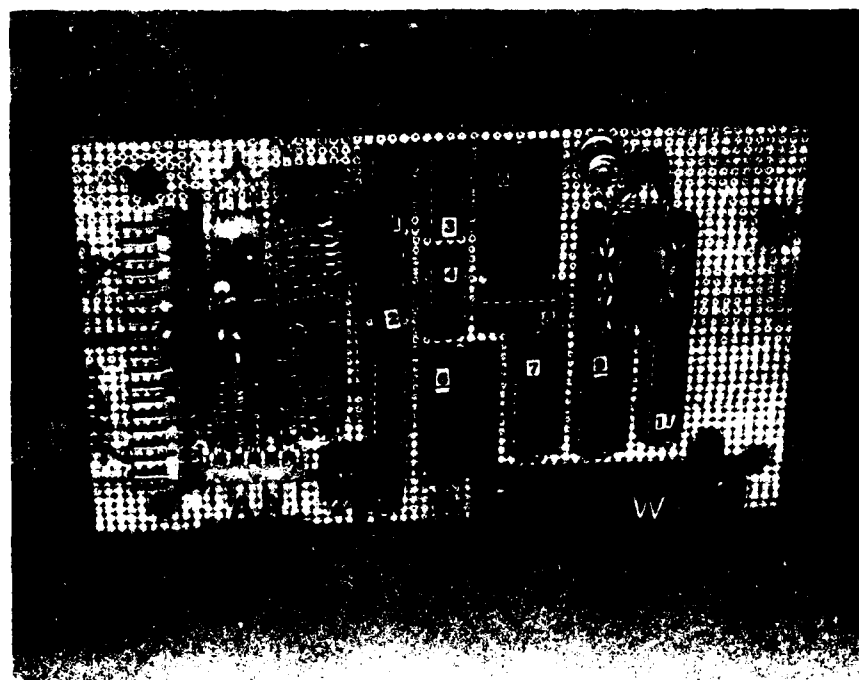


Fig. 11b. Interface Board and Compass

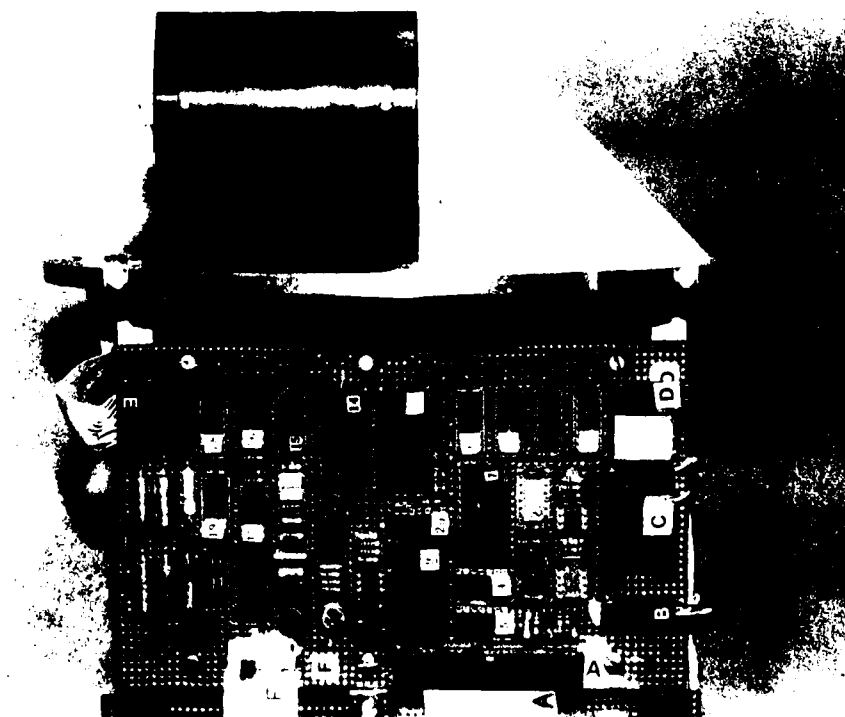


Fig. 12b. Auxiliary Board

(Figure 17b) near the rotation drive, the encoder is magnetically coupled to the rotation drive chain. Mechanical stops on the drive limit the rotation to prevent the ambiguity of two 4 degree positions. The flume transport position is approximately 356 degrees (FDH). This number decreases as the flume rotates counter clockwise. Minimum count, set by the mechanical stop, is approximately 4 degrees (03H). When the flume is parallel to the axis of the CPU housing with the flow from the connector to the blank end cap, the heading is 360 degrees (FFH).

The heading sensor is usually read every 10 seconds. During rotation, the sensor is read 10 times per second. Serial data transmission is used to reduce the number of conductors required. Interface circuitry for the sensor is located on the interface board shown in Figure 11b. Figure 18b shows the Litton sensor, interface circuitry and magnetic coupling. Dwgs. SD-B020 thru 24, contain the schematics and board layouts. The Litton manual contains further information on the sensor.

Power for the sensor comes from the output driver board. Data from the sensor is latched, decoded from gray to binary, and latched in a parallel to serial register using a single pulse from the microprocessor controller. Shift pulses on the CLK line shift the data into a serial to parallel converter on the interface board.

2.14 X-Y-Z Position Sensor

The position of the carriage above the flume is sensed using six General Electric H21-B4 optical interrupter modules. Two modules are mounted on each axis and move with the carriage. Opaque interrupters are mounted on the stationary carriage support. One module on each axis senses when the carriage is in the "zero" position. The other module senses when the carriage passes the

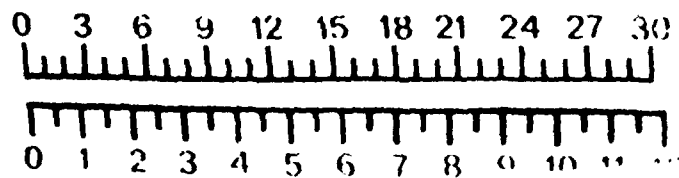
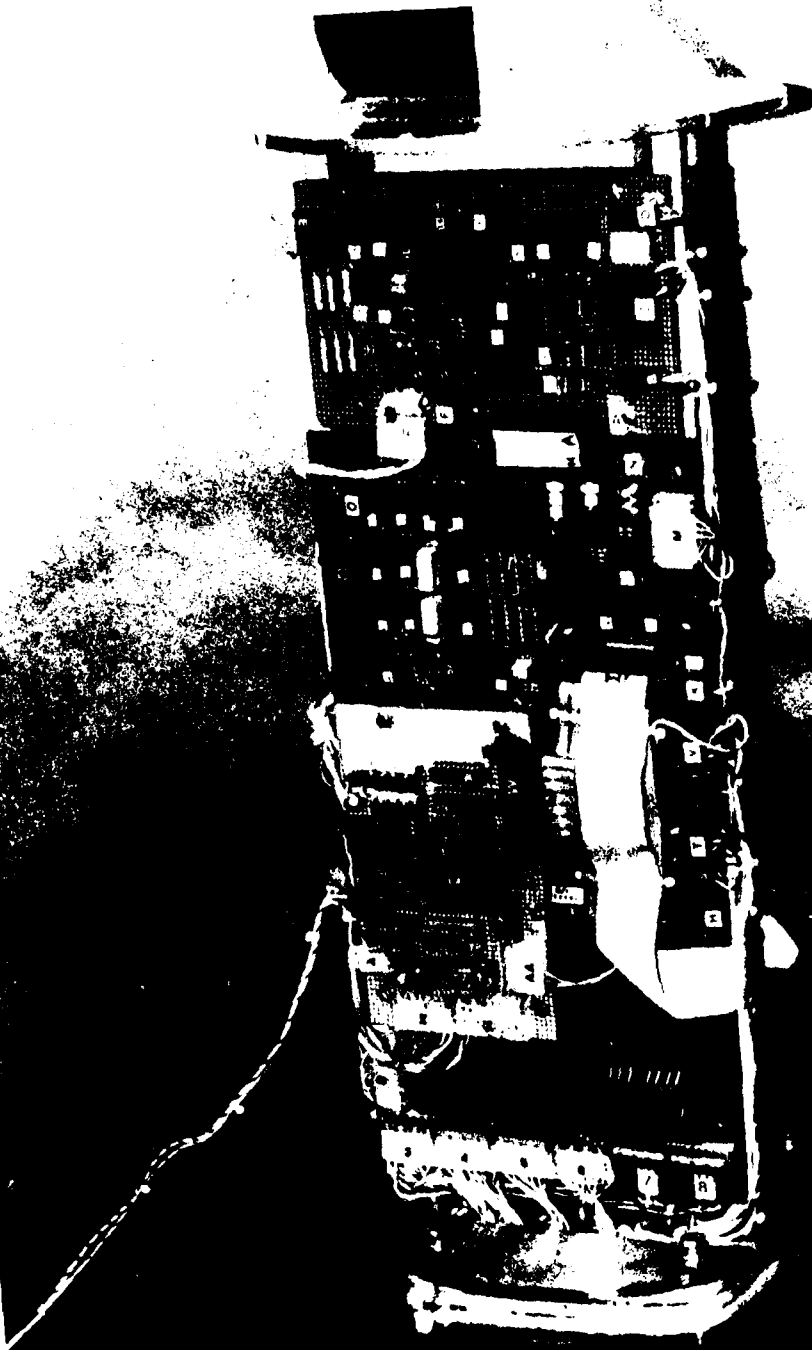


Fig. 13b. CPU Chassis Mounted on End Cap

interrupters. Drawings SD-B011, B025, and B026 present the electrical details of the X-Y-Z optical interrupter system.

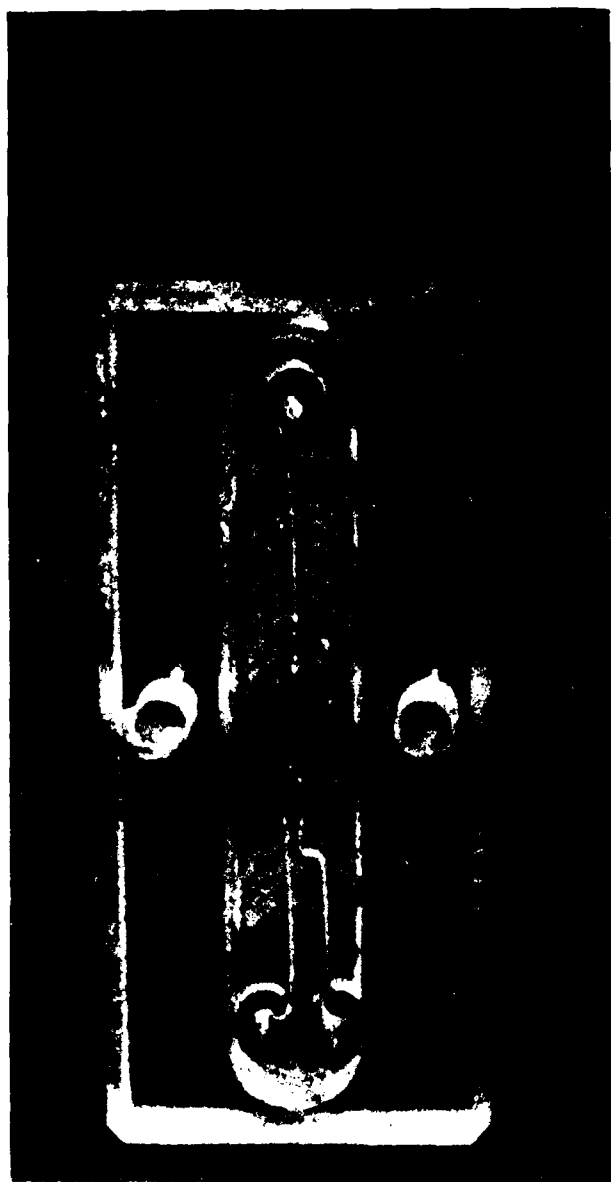
The interface circuit is located on the auxiliary board (Fig. 12b). The board is mounted above the output driver and buffer boards as shown in Fig. 13b. The infrared emitting diodes of each module are wired in series to reduce the number of penetrators in the CPU end cap. A 7 mA regulator is used as a supply for the modules. Low-pass filters and voltage limiters are used on each input. As the carriage passes a stop, a three bit counter is incremented. Seven stops can be counted on each axis. The three bit counter is reset and a fourth bit is set when the counter is in the zero position. The position of each axis is thus represented as a four bit character. The most significant bit (MSB) is used as the zero position indicator. A count of zero indicates that either the carriage is not at the zero position, or that the power to the modules is off.

Power to the interrupter modules comes from the system battery and should always be left on during a deployment. Although power can be switched off by turning off the system batteries, the position counter is reset and a great deal of confusion can result.

When first designed, the interrupter modules were power switched, resetting the X-Y-Z position count. A software fix now keeps power on during the experiment. It is important to reset the counters with the carriage in the transport position ($X, Y, Z = 8$) at the start of each deployment.

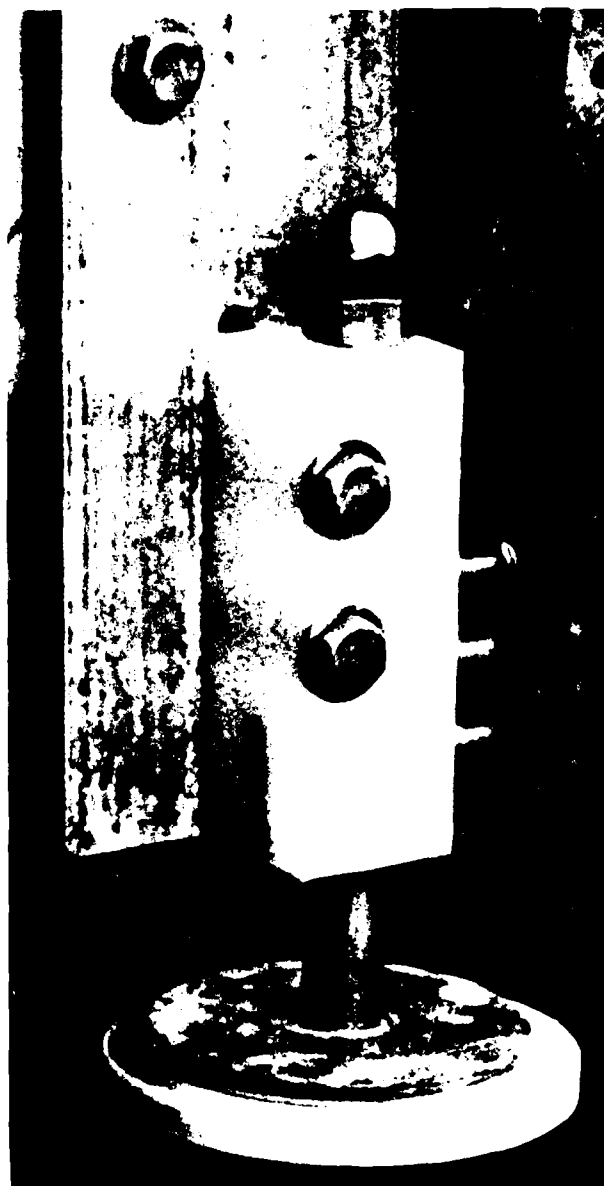
Stray light has been found to prevent proper operation of the modules. Coating the potting with black magic marker ink seems to correct the problem.

Fig. 14b



Flume Insertion Switch

Fig. 15b



Magnetic Sense Switch Detail

Mechanical alignment of the interrupter and the module is critical. When first set in place, the urethane potting creeps and alignment can change. This must be checked to prevent damage to the sensors, which have been broken on occasion by running the carriage without careful observation of the module alignment. Mechanical disturbance may damage the sensor without leaving visual evidence. The system requires a disproportionate amount of attention to keep it working. Improvements should be made before routine use of the Sea Duct is considered.

2.15 Switch Sensors

Four magnetically actuated reed switches are used to sense when the flume test section has been properly inserted into the sea bed. Two other switches are used to detect when the flume is in the transport position, and when the tripod is on the sea floor. One of the four flume insertion switches is shown in Figure 14b. The flat circular plate is lifted relative to its mounting bracket as the flume is inserted. A magnet in the vertical rod actuates a reed switch (Fig. 15b), completing a circuit sensed by the microprocessor. Figures 2b and 3b show two of the insertion switches. The other two switches work in a similar manner but with the circular plate removed. Electrical details of the switch circuits are given in Drawings SD-B011, B025 and B026. A current limited 25 msec. pulse is sent from the auxiliary board to one contact of each of the switches once per second. The switches are sampled at the end of the pulse. The results are stored on tape and also used for decision making by the microprocessor. The switch inputs to the microprocessor are low-pass filtered to prevent false readings from electrical noise.



Fig. 16b. Sea Data Recorder and Level
Sensor Mounting Position



Fig. 17b. Rotation Encoder Pressure Housing

2.16 Acoustic Interface

The Sea Duct may use two distinct acoustic communication systems during deployment. Normal operation uses an Oceanographic Instrument System (OIS) Model 4000 Acoustic Command Transceiver (S/N 2003) for two-way communication between the instrument and the operator. An OIS Model 3000 Acoustic Command System (EHRS). Both units have been modified for use with Sea Duct. The pressure cases of both instruments have been isolated from the electrical ground.

The Model 4000 Transceiver has been modified to allow the Sea Duct controller to send signals to the surface using a five bit serial code (Sixteen codes with a start bit may be sent). This code is repeated once per second for thirty seconds. This signal may be displayed on the shipboard precision depth recorder commonly used by the oceanographic community. Four commands may be received by the transceiver. Transpond enable is the first command (CMD 0), and it must be used to enable the ballast release command (CMD 3). Commands one and two are used for the limited communication with the microprocessor controller. Output pins 1,2 and 3 correspond to commands 1,2 and 3, and are turned on when the command is received. Outputs one and two are twelve volt logic levels through a Schottky diode and a 1K Ohm resistor, and stay on for eight seconds. Output pin three, the ballast release command, is a relay closure to 12 V through a 10 Ohm series resistor. When activated, it remains on for 2.5 hours. A 10K Ohm pulldown resistor and a parallel idiot diode are also on pin three.

The transmitter, or "ping" control, is an optically driven pull down located on the buffer board. Connections between the transceiver and Sea Duct are shown in Drawing SD-B010. Details of the modifications to the tran-

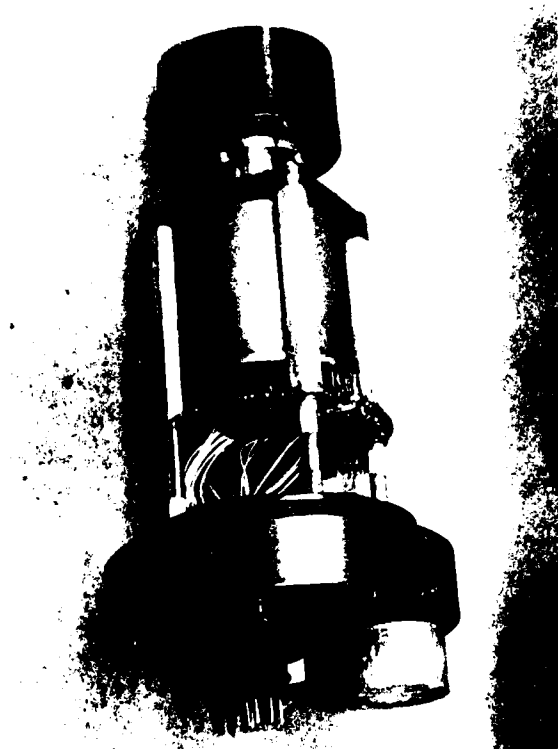


Fig. 18b

Rotation Encoder, Interface Electronics
and Magnetic Coupling



Fig. 19b

SAIL Pump Controller

sceiver and receiver are given in Drawings SD-B038 and SD-B039. Transmit pulse code details are found in the software description.

The OIS Model 3000 Receiver has three outputs corresponding to receiver commands 1,2 and 3. The three outputs are relay closures to 12 V through 10 Ohm resistors. The outputs control ballast release, battery release, and float release in the EHRS system. Drawings SD-C002 and SD-D001 show how the OIS receiver is connected to the system.

Backup timers in the transponder and receiver may be set to release the ballast and the emergency floats after a predefined interval. Both instruments must be reset before they time out to prevent excessive use of the battery. For long idle periods, the instruments should be switched off and the 12 V batteries disconnected.

2.17 Camera System

Sea Duct uses a Photosea Model 2000 Stereo Camera and a Model 1500 SX Strobe to document changes to the sea bed enclosed by the test section. The camera and battery pack can be seen in Figure 2b. The camera system is operated as a stand alone system. The only interface is an optically isolated switch closure as shown in Drawings SD-B011, SD-B012 and SD-B015. The Photosea Camera and Strobe Manual should also be read and understood before deployment.

The camera records time, frame number and a two-digit experiment code on one-half of each stereo pair. A camera frame count is incremented and recorded by the Sea Duct CPU with each "camera" command to synchronize the two systems.

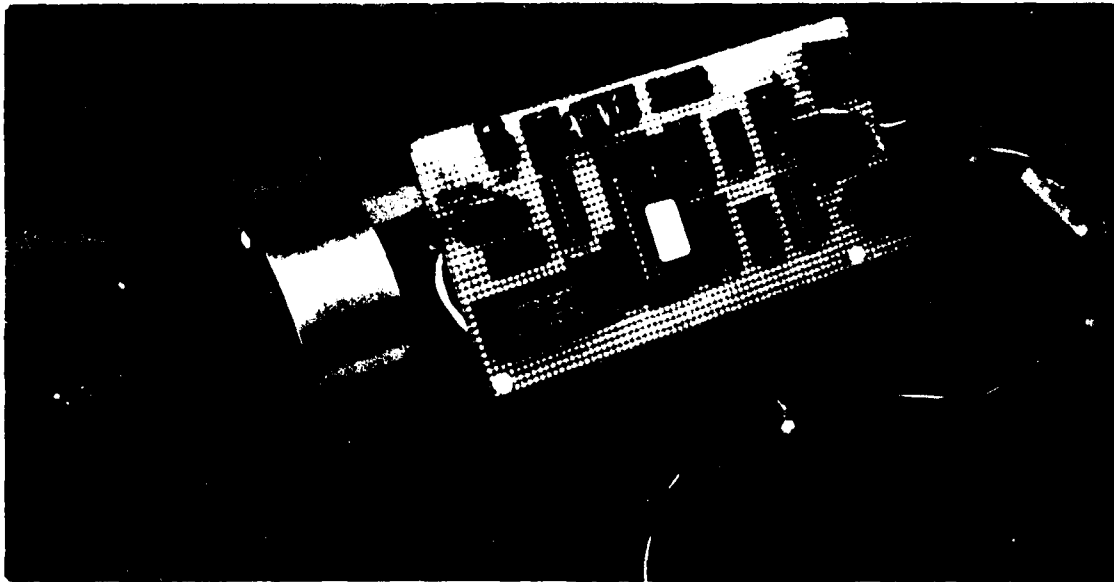


Fig. 20b. Pump Controller Microprocessor and SAIL Interface



Fig. 21b

Pump Controller Power Transistor Mount

2.18 Sea Data Recorder

Data gathered by Sea Duct may be stored on a Sea Data Model 633M/1802 cassette recorder. The one exception is the LDV which uses its own recorder. The recorder is located near the end cap of the CPU housing allowing cassettes to be changed with minimum disturbance to the system (Figs. 8b and 16b).

The Sea Data Model 633 requires two power sources. The microprocessor logic supply delivers + 5 V to the logic circuits. A 6.8 V Zener diode (1N3999A, 10 W) is used in series with the microprocessor battery to supply the nominal 16 V required by the motor. The recorder connects with the system via connector I on the buffer board (DWG. SD-B012). The Model 633 manual contains operating instructions and schematics of the recorder. The 1802 interface supplied with the Model 633M automatically loads data using the direct memory access (DMA) capability of the CPU. A start command is all that is required from the CPU. The 1802 interface requests DMA transfers when the recorder is ready. The recorder may be turned off when not needed. Record format is discussed in the software section.

2.19 Emergency Hydrostatic Release System

The Emergency Hydrostatic Release System (EHRS) controls the ballast release, emergency battery release and emergency float release. The EHRS has its own battery and operates independently from the other electrical systems. Receipt of Transponder Command 3, or Receiver Command 1, releases the three ballast weights. Receiver Commands two and three activate the emergency battery release and the emergency float release respectively. These twelve volt control signals connect to the four relays in the main junction box (Dwg. SD-C002). These relays in turn drive latching relays which connect the 24 volt

EHRS battery to the valve control motors in the EHRS pressure housing. See Drawings SD-D001 and SD-B009.

2.20 SAIL Pump Controller

Two Bryd Industries outboard trolling motors (P/N 600697) are used to pump water in the Sea Duct flume. Power for the motors comes from the system batteries via a high current relay in Box B. A pulse width modulator controls the speed of the two motors. The pump controller is contained in a separate housing (Fig. 19b). SAIL loop 2 is used to send commands to the pump controller. Drawing SD-B036 presents a block diagram of the pump system.

The pump controller is based on a dual pulse width modulator originally designed by A. Bradley. Circuitry and board design are given in Drawings SD-B033 thru 35. The heart of the controller is the Hitachi HD63P01M1 microprocessor. The software used is listed in Appendix H. It is contained in a single 27C32 PROM mounted on the microprocessor. Power on reset circuitry insures both pumps will be off at powerup. The microprocessor and SAIL interface are shown in Figure 20b. The power transistors use an end cap as a heat sink as shown in Figure 21b.

The pump controller receives commands from the Sea Duct CPU system via SAIL loop two. Loop two may be powered down without affecting the pump controller. SAIL pass thru mode (Ref. 2) may be used to talk to the controller using the Sea Duct control loop (SAIL loop 1). The pumps each draw about eighteen amps. The controlling transistors (Motorola MJ-10020) are mounted on the end cap to improve heat dissipation. The transistors can switch up to 50 amps each. All wiring carrying high currents is 10 AWG.

Sea Duct Software

3.0 Introduction

The Sea Duct software is based on the general purpose SAIL monitor program designed by A. Bradley in 1980. Since that time, numerous revisions have been designed and implemented by A. Bradley, S. Liberatore, W. Terry and others. The monitor program is easily adapted for use in new designs, and has been used by the oceanographic community in at least twelve instrument designs. Originally designed for RCA 1800 series microprocessors, the monitor has been adapted for use with the 6801 family including the 6301 and 6811.

The monitor is divided into two distinct segments which interact through a common global memory page. One segment is interrupt driven and contains all instrument specific processing functions. The second segment, operating outside of the interrupt, contains the basic monitor and instrument specific communication functions. The interrupt is driven using a clock derived from a crystal oscillator and a divider. An optional software Real Time Clock (RTC) module eliminates the need for time-keeping hardware.

Another option allows the use of a high level language or pseudo-program code (PPC) to control the instrument in a predefined sequence. This sequencer allows complex functions to be called at specific times using an easily modified instruction list. Two other simple monitors are also available for instrument development and testing. The first monitor, BLT2, (Bradley, Liberatore, Terry monitor Vers. 2) employs a software UART to allow testing of a minimum configuration system. BLT2 uses the 1806 Q output and EF4 input. Normally not used with Sea Duct, it is occasionally useful in debugging the system. It is described in Appendix K. The second mini-monitor (BTU) resides

in Sea Duct memory and is automatically invoked during a hardware or power-on reset. In addition to basic monitor functions, BTU controls an on-board PROM burner, RAM test, and other tasks not available with the main monitor. A description of the BTU monitor is contained later in this text.

Extensive working knowledge of the RCA 1806 microprocessor, 1800 series peripherals, and SAIL is not required for normal Sea Duct operation and sequencer programming. Some portions of the following descriptions assume the reader is familiar with these subjects. Modifications and additions to Sea Duct functions generally require an understanding of the hardware - software interfaces, various software module interactions, as well as an understanding of the above subjects.

3.1 Monitor Command Description

The Sea Duct monitor communicates using a SAIL (IEEE-997) 20 ma. Loop (Ref. 14,30). The protocol is 300 baud using 7 data bits, even parity, and 1 stop bit. Any 'dumb' video terminal, lap computer, or personal computer with a RS-232 communications port may be used. A 20 ma. loop supply and RS-232 interface are required (Refs. 3,19,34) monitor functions are presented in the monitor software description.

In the following discussion, **Bold type** is used to indicate commands and responses typed by the operator. Regular type indicates responses from the instrument.

The instrument's SAIL address is #SD. The unit may be addressed as follows:

```
#SD
Sea Duct  Vers. 5.9
:
```

The ":" is the system prompt. Note that a carriage return (CR) is not typed after the address. When the Sea Duct CPU is first powered-up, a ";" prompt appears indicating that the BTU monitor is running instead of the system monitor. The BTU monitor is always addressed, and in that respect, does not properly adhere to SAIL protocol. Type !R#SD to switch to the Sea Duct system monitor. A description of the BTU monitor may be found later in the text.

When in use, the system monitor must be addressed to communicate with the instrument. The SAIL loop will unaddress if the loop is broken, the loop is readdressed (a # is typed), or the monitor detects a parity or framing error.

System Commands are:

H Help - Gives the command summary:

Help:

Sea Duct Vers. 5.9

System Cnds: !UNLOCK; !LOCK

Memory Commands:

!Maaaa dd...; ?Maaaa nnnn; ?C (CRC)

M (Memory protect)

Clock Commands: ?T; !TIME DDDHHMMSS @

Pass Thru Mode: %P; %R; %X; %B

Sequencer Cnds:

?S; !S; !F (Follow PPC)

Main Sequencer PPC Starts at 3000

Sea Duct Cnds:

?H; !H (Read or Set Exp. Hdq.)

?E; !E (Read or Set Exp. #)

?B (?Buffer)

:

!UNLOCK Enable memory write functions

!LOCK Disable memory write and \$ functions.

?C Cyclic Redundancy Check (CRC).

This command calculates a 16 bit CRC over a block of memory. It may be used to verify the integrity of an area of memory. For example, the number generated

by the CRC may be compared with the CRC generated at an earlier time such as when a new EPROM is burned or a temporary program is loaded in RAM. CRC's for new program EPROMs should be noted on the device as well as in a notebook.

The monitor will ask for a starting address and the number of locations (hex) for the CRC calculation. For example:

```
:?CRC from 800 over 800
CRC = DE86
:
```

gives the CRC starting at memory location 0800 over 800 locations (Both numbers are HEX). It takes about one minute to do the entire 64k memory; about 3 seconds to do one 2K memory block. The routine is based on a standard polynomial for generating CRC's. A description of the CRC algorithm may be found in Appendix E.

?Maaaa nnCR Display memory at address aaaa for nn locations. To interrogate memory, the user types a command such as

```
?MF5 3
```

terminating with CR (carriage return). In this case the system responds by printing out the contents of memory beginning at location 00F5. Three bytes are printed out as two hex digits each. Each line of output begins with the address, and data is grouped in 2-byte (4-digit) blocks. When necessary, new lines are begun every 16 bytes, with the previous lines ending in semicolons. The user may enter any number of digits to specify the beginning location (leading zeroes are implied, if necessary). If more than four digits are entered, only the last four are used. The number of bytes to be typed out should be in hex. Again, if more than four digits are entered, only the last four are used. This feature allows the user to correct a mistake. One simply keeps typing, putting in the correct 4-digit values (230024 is effectively 0024).

!Maaaa ddee... Load Memory at address aaaa

In general, data is entered into memory by means of a command such as:

```
!M2F 434F534D4143
```

This example enters six bytes (two hex digits each) into memory beginning at location 2F. It is normally

terminated by a CR. Once again, the starting location is determined by the last four digits entered. Data is entered into memory after each two hex digits are typed. If the user types an odd number of digits, the last digit is ignored, and the error message '?' is typed out.

The !M command provides two options that facilitate memory loading. First, a data string can be extended from line to line by typing in a comma just before the normal CR. (In this case the user must type CR-LF [carriage return-line feed] before he can begin a new line.) For example:

!M23 56789ABC,(CR) (LF)

DEF0123456,(CR) (LF)

3047(CR) () are not typed.

enters 11 successive bytes beginning at location 0023. Between successive hex pairs while data is being entered, any non-hex character except the comma (and semicolon, as will be discussed) is ignored. This arrangement permits arbitrary LF's, spaces (for readability), etc.

As a second optional form of data entry, a string of input data can be terminated by a semicolon (and a CR). The utility program then expects more data to follow on the next line, but preceded by a new beginning address. The line must have the format of an !M command, but with the initial !M omitted. This option provides the mechanism for reading a program from an external device. Note also that the semicolon feature on input allows non-contiguous memory areas to be loaded.

!OPEN SYS Enable the \$ Command.

The system must be in the unlocked state.

\$aaaa Run program at address aaaa.

DO NOT USE THIS COMMAND unless you are intimately familiar with the program and all memory allocation.

As an example:

\$10D6(CR)

starts execution at location 10D6 with R3 as the program counter after inquiring if the address is correct and you are quite sure that you really want to risk it.

\$P always begins with Register 3 as the program counter and X=R2. This arrangement is consistent with the fact that P=3 and X=2 during normal monitor operation outside of interrupt. The last-four-digits-in rule applies to the address typed in.

!TIME DDDHHMMSS@ Set Time

The system Real Time Clock (RTC) is set with this command. The last nine digits entered are the values used. The "@" sign is typed at the exact time entered with the nine digits. The time can be entered as local or Universal; however, when questioned, it will always type a "Z". Let the user beware! For example, say you want to set the RTC to day 14, 14:25 hrs, 23 sec. Type:

:!TIME 014142523@#SD

The "@" is typed at the exact time just entered. The system now must be readdressed "#SD". The command uses the last nine digits entered to allow for correction of mistakes.

?T ?Time

The system real time clock can be read using this command. For example:

:?T... 014 14:25 05 Z...@

The time is printed approximately five seconds before the @ sign. The time is correct when the "@" sign is printed.

!S Sequencer Control

This command is used to start, stop or redirect the sequencer. Typing

**:!Sequencer On ? Y at PPC ~ 6000
6000, Ok ? Y
:**

will start the sequencer at memory address 6000H.

```
:!Sequencer On ? N      (or any character other than Y)
:
```

will return the sequencer to the idle loop. To prevent stopping or redirecting the sequencer when !S is typed, CR or _ (space bar) may be typed after PPC =.

```
:!Sequencer On ? Y at PPC = (CR)
Continue ? Y
:
```

The above example allows the sequencer to continue with no interruption. If N is typed after Continue ?, the command is effectively started over:

```
:!Sequencer On ? Y at PPC = (CR)
Continue ? N
Sequencer On ? Y at PPC = (CR)
:
```

Note that the space bar and (CR) may be used interchangeably. The address uses the last four digits typed convention.

?S Query Sequencer status.

This command will display the address of the sequencer Pseudo Program Counter (PPC), Return STack, and Arithmetic STack. If the sequencer is in the idle loop (sequencer off), the following is displayed. The PPC address will be either 0F00 or 0F01.

```
:?Sequencer PPC = 0F00 Rstk = 523F Astk = 527F
```

For the Sea Duct, values Rstk = 523F, Astk = 527F indicate that nothing has been placed on either stack.

If the sequencer is in a subroutine, Rstk will display the address of the next available sequencer return stack position.

```
:?Sequencer PPC = 3409 Rstk = 523D Astk = 527F
```

The Astk value is the address of the last value placed on the Astk. Additionally, up to 15 Astk values will be displayed.

```
?Sequencer PPC = 6004 Rstk = 523F Astk = 527D 22 11
```

In this case location 527D = 22, 527E = 11.

!F Follow the PPC counter.

This command will display the address of the current PPC until the loop is broken. Pseudo Program Commands requiring multiple words will only have their first address location displayed.

```
:!Sequencer On ? Y at PPC = 3000
3000, Ok ? Y
:!Follow PPC
3001 3003 3005 3007 3009 300B 300D 300F 3409 340E
```

Here the sequencer is started at PPC = 3000. The !Follow routine is started immediately after that, but the sequencer has reached 3001. Several two byte PPC instructions are shown. A jump to PPC = 3409 follows.

If the sequencer is in the idle loop, !F will display :

```
:!Follow PPC
0F01 0F00 0F01 0F00 0F01 0F00 0F01 0F00 0F01, etc.
```

When following the sequencer PPC's the monitor will neither recognize the readdress character (#) nor will it look for parity errors. Short of resetting the instrument, breaking the loop is the only way to stop this command. Therefore, use of this command does not strictly adhere to the SAIL protocol.

3.2 Summary of Standard Command Usage

In summary, after addressing the system:

#SD

Sea Duct Vers. 5.9

:

the user may type:

H

?M(hex address)_(count)CR

!M(hex address)_(data)[optional , or ;]CR

— = space where the data may have non-hex digits between each hex pair.) The space bar may also be used for CR in some cases.

\$(address)CR

1. For **?Maddr**, a hex count must follow (again, only the last four digits are kept), and the command is terminated by CR.
2. For **!Maddr**, data must follow. An even number of hex digits is required. Before each hex pair arbitrary filler (except for CR, comma, or semi-colon) is allowed. CR terminates the command, unless it is immediately preceded by a comma or, as is generally the case, by a semicolon.
 - a. In case of commaCR the user must insert an LF for the monitor to continue to accept data. This procedure is a form of line continuation.
 - b. In case of a semicolon all following characters are ignored until the CR is typed. Then, the user must again provide an LF, and the monitor UT4 continues as if it had received optional filler, then a starting address, then a space, and then data.
 - c. The **!M** command can be followed by as many continuation lines as needed, mixed between the two types if desired, and is finally terminated with a CR not preceded by a comma or semicolon.
3. Command **\$** must be followed by starting address (last four digits used if more than four are typed in). If no address is entered, 0000 is assumed. Program execution begins at this location with R3 as program counter with X set to 2.

4. When a !M or ?M command is accepted and completed, the system types another prompt character.
5. When the monitor detects bad syntax, it types out a ? and returns the carriage. If a mistake is made when data is entered (by typing in an odd number of digits), all data will have been entered except the last hex digit. Note that the "only-last-four digits" rule in the address field allows the user to correct an error without retyping the whole command. For example, a mistaken 234 can be corrected by continuing 2340235=0235. A bad command can be aborted by typing in any illegal character except after !M or ?M or between input hex data pairs. In these cases, the user should type any digit and then, for example, a period.

3.3 SEA DUCT Specific Commands

M Memory Protect

Sea Duct RAM may be set on a page by page basis as READ ONLY or READ/WRITE. RAM that must always be write enabled (buffers, stacks, etc.) cannot be protected with this command. One page is equal to 100 H or 256 D memory locations.

?B ?Buffer

The buffer written to the Sea Data Recorder may be displayed with this command. A wait of several seconds may occur as the display shows what was just written on the tape. The recorder may be off but the display will still appear. If the A/D or transmissometer are off, their display will show 0's. For example:

```
:?B WAIT...
```

```
Buffer:
```

```
EXP# 0 703/09:18:30 PPC=0F01
ERR=00 ACU=00 SW=00 POD=00 CMPS=73
HDG=00 P1=00 P2=00 CAM=00
PITCH=57 ROLL=5B uP Bat=D1 SysBat=05
GND=009 REF=3F7 +5V=FE0
XPOS=8 YPOS=8 ZPOS=8
DE4 DE3 DE3 DE2 DE1/DE2 DE3 DE4 DE5 DE4
:
```

The first line displays a four bit Experiment #, the Date/Time DDD/HH:MM:SS and the sequencer PPC address. The second line shows ERROR word, ACOUSTIC status,

Switch status, POD status, and COMPASS word. The third line gives flume Heading, the two flume pump speeds, and the camera count. The fourth line gives the PITCH and ROLL values and the battery voltages measured by the A/D. The next line is the A/D references. The sixth line gives the position of the camera carriage. The two battery voltages are 1/6 their actual values. The last line is the transmissometer values for seconds n1 through seconds n+10. N+10 is the value taken at the time shown. All values are HEX, with the exception of the Date/Time, which is BCD.

!H !Heading

This command sets the value for the flume heading to be used during the experiment. The heading is the direction from which the flow comes. For example:

```
:!Heading (HX) Flow from = ? 20
```

sets the heading to 20 (hex, = 45 deg.)

```
:!Heading (HX) Flow from = ? 23420
```

does the same thing as only the last two digits entered are used.

?H ?Heading

This gives flume heading that will be used during the experiment. The heading is the direction from which the flow comes.

```
:?Heading = 20 (HX)
```

!E !Experiment Number

This command sets the value for the optional experiment number to be used for the experiment. One hex character (0-9,A-F) is allowed. For example:

```
:!Exp. # (HX) = ? 2
```

sets the number to 2 (hex).

```
:!EXP. # (HX) = ? 35BA2
```

does the same thing as only the last character is used.

?E ?Exp.

This gives the value of the experiment number.

```
:Exp. # = 2
```

3.4 Sea Duct 1806 Microprocessor Configuration

Register allocation used in the program follows conventions suggested by RCA (Refs. 27,28). Figure 22b contains the register allocation used. Only dedicated registers are listed. Miscellaneous uses of undedicated registers are too numerous to list.

The 1806 instruction set allows efficient subroutine calls and returns without using the RCA SCRT (Standard Call and Return) normally required by the 1802 (Refs. 27,28). Calls may be made using any register as the program counter. This allows subroutines to be called from inside interrupt routines (PC = 1) as well as outside interrupts (PC = 3). Although the RCA SCRT routines were used in earlier versions of the monitor, they are no longer present in the program.

Figure 23b presents the memory map of the computer. 2716 EPROMs, 6116 RAMs, and Mostek MK48Z02B zero power (battery backed) RAMs are used as explained in the hardware section. The BTU monitor EPROM resides in the first 800H locations. Three Sea Duct main program EPROMs occupy locations 0800 - 1FFF. The extended sequencer program resides in locations 2000 - 27FF. Memory locations required for housekeeping locations such as stacks, buffers and the global page use two battery backed RAMs in locations 5000 - 5FFF. The main sequencer program used during deployments routinely starts at location 3000. Individual sequencer commands for testing reside in locations 3800 - 3FFF. The sequencer memory is battery backed RAM. General purpose RAM is in locations 7000 - 77FF and E000 - E7FF. General purpose battery backed RAM is in locations 6000 - 67FF and 8000 - 87FF. The socket for memory locations F000 - F7FF doubles as a EPROM programmer although an external power supply is re-

Figure 22b

SEA DUCT

1806 CPU REGISTER ALLOCATION

SAIL REGISTERS

Register	Mnemonic	Function
Reg. 0	DMA	DMA IN/OUT - ALSO START
Reg. 1	INTPC	INTERRUPT PROGRAM COUNTER
Reg. 2	STACK	PROGRAM UTILITY STACK
Reg. 3	PC	MAIN PROGRAM COUNTER
Reg. 4	---	SCRT CALL * RCA SCRT NOT USED BY *
Reg. 5	---	SCRT RETURN * THIS PROGRAM *
Reg. 6	RTNPTR	POINTER FOR RETURN & IMMEDIATE BYTES
Reg. 6	LIST	" " " " " "
Reg. 7	GPAGE	GLOBAL PAGE (R7.1 REMAINS CONSTANT)
Reg. 8	CYC CNT	REAL TIME CLOCK CYCLE COUNT, MISC.

Registers A - F and 7.0 are saved and restored by the interrupt and restore from interrupt routines. Registers 8 - F may be used for miscellaneous tasks outside of the interrupt during one RTC cycle.

INTERRUPT REGISTERS

Register	Mnemonic	Function
Reg. 0	DMA	DMA IN/OUT
Reg. 1	INTPC	INTERRUPT PROGRAM COUNTER
Reg. 2	STACK	PROGRAM UTILITY STACK
Reg. 3	RTNPTR	POINTER FOR RETURN & IMMEDIATE BYTES
Reg. 4	---	" " " " " "
Reg. 5	---	" " " " " "
Reg. 6	GPAGE	GLOBAL PAGE (R6.1 REMAINS CONSTANT)
Reg. 7	---	" " " " " "
Reg. 8	INTPC	INTERRUPT PROGRAM COUNTER
Reg. 9	STACK	PROGRAM UTILITY STACK
Reg. 10	RTNPTR	POINTER FOR RETURN & IMMEDIATE BYTES
Reg. 11	---	" " " " " "

Registers 0 - 11 are saved and restored by the interrupt to interrupt routines. Registers 12 - 15 are used during an interrupt to hold the return address and the return address. Registers 16 - 19 may be used for miscellaneous tasks outside of the interrupt during one RTC cycle.

AD-A107 734

SEA DUCT: A DEEP-SEA COMPUTER-CONTROLLED RECIRCULATING
FLUME FOR THE STUD. (U) WOODS HOLE OCEANOGRAPHIC
INSTITUTION MA C L NINGET ET AL. AUG 87 WHOI-87-1

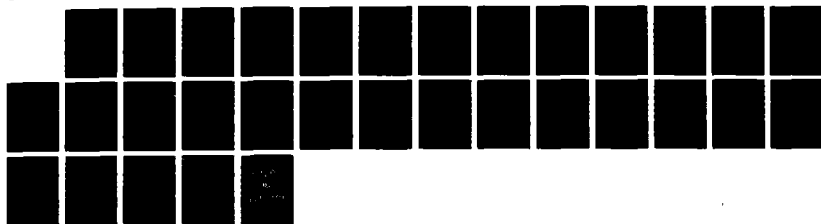
3/3

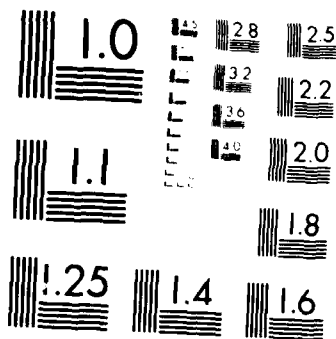
UNCLASSIFIED

NO0014-85-C-0001

F/G 8/3

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Figure 23 b.

Sea Duct Memory Allocation

	0xxx	1xxx	2xxx	3xxx	4xxx	5xxx	6xxx	7xxx
x000	BTU2 Monitor	Prog. PROM	Extd. Seqncr	B-RAM Seqncr Progs	None	B-RAM	B-RAM	B-RAM
x100						Global		
x200						Page		
x300						Seq		
x400						Stack		
x500								
x600								
x700						BLT2 RAM		
x800	Prog PROM	Prog PROM	None	B-RAM Seqncr Indiv. PPCs.	None	B-RAM	None	None
x900								
xA00								
xB00						Record		
xC00						Buffer		
xD00								
xE00								
xF00								

Also: B-RAM • 8000-87FF, RAM • E000-E7FF

quired. A few locations in the memory space above F800 are required by the CDP 1877 interrupt controller.

3.5 Global Page

Most variables routinely used by the program are stored on a single memory page (100H or 256D locations) referred to as the global page. Variables are stored as defined by an equate table which is a file included with the program source at assembly time. The memory locations stay the same with each assembly.

The global page simplifies communications between the monitor (outside interrupts) and system functions (inside interrupts). For example, a flag or data value can be set by the monitor and used during interrupt. A screen dump of the global page can describe almost every system state in a concise form.

The Sea Duct global page is 5000 thru 50FF. This is defined on the equate table included with the program source during assembly. The equate table include file is SDEQU.MAC. A copy of the equate table may be found in Appendix C.

3.6 Power Up and Hardware Resets

Hardware and power-on resets are identical in the Sea Duct microprocessor system. When reset, the system will respond with a `;` prompt, which signifies that a start-up monitor is running in place of the normal system monitor.

The monitor running at start-up is the BTU monitor developed by A. Bradley and W. Terry. The monitor uses a subset of the commands found in the regular

Sea Duct monitor. Typing an H (for Help) will display the command list. Commands common to both monitors have been described in the Sea Duct Monitor Section.

The argument rules are similar to those used with the main monitor. When the monitor expects a constant, all non-hex entries are ignored except space and CR, either of which terminate the entry. (Don't use CR since the subsequent reply will overwrite the beginning of the line.) Leading zeroes are provided and excess hex digits may be added to correct an entry error since only the last valid hex digits are used. Examples of valid entries are 0001, 20, 3WG5 (=35), ABC34EF2 (=4EF2).

Commands unique to the BTU monitor include:

.M Block Move. Format, ".Move from AAAA to BBBB length CCCC ok?Y" where AAAA, BBBB, CCCC are source start address, sink start address and length to copy. If the reply to "ok?" is not "Y", no move will occur. "Move" copies from low to high address and can get into trouble if the source and sink overlap. It is important to remember that memory can only be moved into RAM.

.V Verify. Format, ".Verify AAAA with BBBB length CCCC:."

This command compares two blocks of memory and lists the differences. The format of non equal data is AAAA BB CC DDDD where BB is the byte at AAAA and CC is the byte at DDDD and BB<>CC.

.R Ram Test. Format ".Ramtest start at AAAA over BBBB".

Ramtest tests an area of RAM starting at AAAA by writing a pseudo-random sequence BBBB bytes long, then checking the entire area on a second pass. It is very good at finding obscure "connected cell" errors. Every good pass causes a * to be displayed on the terminal. Each subsequent pass uses the

sequence shifted over one bit so several are required to catch all bit locations. When RAM test finds an error, it lists the exclusive or of the data it wrote and read along with the address where the error occurred.

!R Run Target System. !R starts the Sea Duct Monitor. The monitor will start in the unaddressed state. To address the Sea Duct, the address **#SD** must be sent.

The BTU monitor does not adhere strictly to SAIL protocol. With BTU the system is always addressed. Other SAIL conventions are followed.

BTU uses a global page with a different address (5700-57FF) than the global page used by the Sea Duct monitor. Resetting the system will not affect the Sea Duct global page. It is possible to use this feature to debug problems in the Sea Duct system.

3.7 Microprocessor Interrupt System

Timekeeping functions including the real time clock are controlled by a crystal driven interrupt system. The interrupt rate is 40 Hz, or one cycle every 25 mSec. Each interrupt in a given second is called a cycle.

As mentioned earlier, the majority of all Sea Duct specific processing occurs during an interrupt; all monitor and communication functions occur outside of the interrupt cycles. When modifying the main program, it is important to keep time spent in tasks inside the interrupts short enough to be completed and return from the interrupt allowing time outside the interrupt for monitor functions. This requirement has been easy to meet during programming of the system. Programming of the sequencer in either pseudo-code or the higher level Sea Duct language is not restricted in this manner.

When the microprocessor recognizes an interrupt, the 1806 program counter changes from Register 3 to Register 1 (Figure 22b). Register 1 points to the start of the interrupt housekeeping functions which enable the system to continue where it left off at the time the interrupt was recognized. Register 1 is set up at the start of the program and returned to the start of the interrupt program at the end of each interrupt cycle.

The Sea Duct hardware includes a RCA CDP 1877 Programmable Interrupt Controller (PIC) to vector interrupts. The only vector used is number zero. The interrupt vectors are at label INTPGM: in the program listing (Appendix C). INTPGM: is forced to location 0800 H. The actual interrupt housekeeping starts at label INTRP:. In addition to Registers X,P,D, and DF, the contents of Registers E,D,C,B, and A are also saved. The lower half of Register 7 [R(7.0)] is also saved. The higher half of Register 7 [R(7.1)] remains constant as it defines the global page. Microprocessor output Q is pulsed at this time for use as a debugging tool. The contents of Register B used during the previous interrupt are also restored.

3.8 Long Branch Table

The Long Branch Table (LBT) refers to a table of tasks that defines what is done during a specific interrupt cycle. Each interrupt task is entered from and returns to this table. The Long Branch Table is kept in the same memory location with each version of the program. Because each interrupt task is entered using a Long Branch (LBR [C0xxx]) the module can easily be skipped over for testing purposes by using a Long Skip (LSKP [C8xxxx]) instruction. Using a logic analyzer to monitor progress through the LBT is easier than trying to follow the program through a path that may change with each assembly.

The following paragraphs give a brief description of each task controlled by the Long Branch Table:

3.9 Real Time Clock @ Check (ATCHK:)

The @ sign is sent on the SAIL loop by the Real Time Clock (RTC) as a time tic. When the clock is queried, the time is sent on the loop approximately five seconds before the time tic. The real time clock puts a flag on the global page that is checked by this module. When ATCHK sees the @ flag, it sends the @ on the loop. This module is placed at the start of the interrupt cycle to insure the time tic does not vary. ATCHK is considered to be part of the Real Time Clock.

3.10 Real Time Clock (RTC:)

The Real Time Clock is considered to be part of the monitor although it controls all time dependent functions of the Sea Duct System. The RTC time word is stored on the global page and consists of three day characters, two hour characters, two minute characters, two second characters and an eight bit cycle counter. With the exception of the cycle count, the characters are each four bit BCD characters. The cycle count is a single eight bit hexadecimal word. The cycle count is incremented on each interrupt and ranges from 0 on the first interrupt of a new second to 27H (39D) on the last cycle of the 40 Hz interrupt. Any portion of the RTC time word on the global page can be read by other modules to make decisions on starting, etc. For example, sequences repeating every other cycle, every second, every second on the fourth cycle, etc., can easily be obtained. Instructions for setting and reading the RTC can be found in the description of the Sea Duct Commands.

3.11 Sequencer Cycle (SEQCYC:)

Typically, a single sequencer pseudo program code (PPC) is executed each

second during cycle 1. Some PPCs require re-entry on more than one cycle and, in some cases, require more than one second to complete a task. This information is included in the assembly coding of each PPC. SEQCYC determines if the current PPC should be re-entered, left idle, or a new one started. The PPC sequence rate (SEQRAT), an up-down counter showing the number of times to run or times run with the current PPC, and a flag for a fast testing mode are available on the global page.

3.12 SAIL, Loop 2, Controller (TTY2:)

TTY2 handles communication with instrument on SAIL Loop 2. At the present time the only instrument on Loop 2 is the flume pump control. TTY2 checks a list set up by sequencer PPCs and sends them the Loop 2 UART at the appropriate time. Rudimentary receive instructions are also included. Loop 2 communications using the Pass-Thru-Mode are not handled by this module.

3.13 Break Loop 2? (BR2:)

This routine is used to continue to break the secondary SAIL loop and rest UART2 when finished. The start of the break is controlled via the Pass-Thru-Mode.

3.14 Sequence Counter Timeout (CTCHK:)

When any of the three sequencer counters are in the count mode, this module decrements the counter once per second. When the counter reaches zero, this module redirects the PPC. This function is explained in the sequencer description.

3.15 Read the Compass (CMPSRD:)

During the first second (SS = x1) of each ten second period, the compass is read. The compass is powered up during cycle 0A. It is read and powered

down 25 msec. later during cycle 0B. The compass word is stored on the global page.

3.16 Read the Sense Switches (SWRD:)

The mechanical sense switches are read once each second. Power to the switches is turned on during cycle 24. The switches are read and powered down during cycle 25. One improvement for future revisions would be to record if the switch was closed during any second of the ten second period. The switch word on the global page would be reset after the buffer was written to the tape.

3.17 Analog to Digital Converter Control (AD:)

A/D control (on/off) is accomplished with sequencer commands. When off, the A/D is powered down and zeros are written into the A/D data locations on the global page. When on, the A/D runs only during seconds (SS = x0). This module reads a multiplexer control list (MUXLST:) and a storing location list (MEMLST:) which direct the A/D power mode (on, start, off), the sensor to be read, and where the individual datum will be stored. The A/D is powered up during cycle 00 and data conversion started during cycle 07. The multiplexer is set during odd cycles; the A/D is started and read during even cycles. Eight bit data may be stored to save tape, and this is controlled by MEMLST. After cycle 15, the multiplexer is set to the transmissometer.

3.18 Transmissometer Control (TR:)

On/Off control of the transmissometer is also achieved with sequencer commands. The A/D must also be enabled for proper operation. The transmissometer is read once each second. The multiplexer is set and A/D powered during cycle 17; the A/D is started during cycle 18; and datum is read and stored in

the proper location during cycle 19. The transmissometer itself is powered up during cycle 02 of the first second of a ten second group (SS = x1). It is not powered down until the transmissometer system is turned off.

3.19 Relay Pod Check (PDCHK:)

Once each second during the cycle 27, the sense lines from each relay pod are read and stored on the global page. If any of the six functions controlled by each pod is on, the corresponding bit will be set in the relay pod status word on the global page. The individual bits may be set during any scan of the pods. The word is reset only after the buffer is written to the tape at the start of a few second period.

3.20 Heading Indicator Check (HDCHK:)

Normally the flume heading (flume rotation position) is read once every 10 seconds (SS = x9) and stored on the global page. During rotation, the heading is read ten times per second by the sequencer. This routine only turns on the power to the rotation encoder; the heading is read ten times per second by the sequencer.

3.21 Relay Pulse Driver (PULCHK:)

Latching relays are used to control various functions of the Sea Duct mechanical system. The relay's coils are driven by electrical pulses from the output driver board. This software module checks a flag on the global page (PULFLG) to see if a pulse has been requested by the sequencer or other software. If the flag is active (PULFLG = AC), this routine checks to see which relay should be pulsed (PULNUM) and how long to continue the pulse (PULCNT). This routine thus allows any relay to be pulsed in increments of 25 msec. by any sequencer PPC or other software module.

Buffer Addr.	Byte #	Data
5B00	01	Exp. #, Day 100
01	02	Day 10, Day 1
02	03	Hour 10, Hour 1
03	04	Min. 10, Min. 1
04	05	Sec. 10, Sec. 1
05	06	PPCHI
06	07	PPCLO
07	08	ERROR Word
08	09	ACSTAT
09	10	SWSTAT
0A	11	PODSTAT
0B	12	CMPSS
0C	13	HDG
0D	14	PUMP1
0E	15	PUMP2
0F	16	CAMCNT
5B10	17	PITCH
11	18	ROLL
12	19	uPBAT
13	20	SYSBAT
14	21	ADGND HI 8
15	22	ADGND LO 4, ADREF HI 4
16	23	ADREF LO 8
17	24	AD+5V HI 8
18	25	AD+5V LO 4, XPOS
19	26	YPOS, ZPOS
1A	27	T1 HI 8
1B	28	T1 LO 4, T2 HI 4
1C	29	T2 LO 8
1D	30	T3 HI 8
1E	31	T3 LO 4, T4 HI 4
1F	32	T4 LO 8
5B20	33	T5 HI 8
21	34	T5 LO 4, T6 HI 4
22	35	T6 LO 8
23	36	T7 HI 8
24	37	T7 LO 4, T8 HI 4
25	38	T8 LO 8
26	39	T9 HI 8
27	40	T9 LO 4, T10 HI 4
28	41	T10 LO 8

Figure 24 b. Sea Data Buffer Memory Allocation

3.22 Check Carriage Position (XYZCHK:)

The position of the camera and LDV carriage above the test section is routinely monitored once every 10 seconds. The position is read during cycle 25H of second nine (SS = x9). When the carriage is being positioned by the sequencer, the position is monitored every 25 msec. by the sequencer and not by this module. Carriage position is stored in locations XPOS and YZPOS on the global page. Each position is recorded using a four bit character.

Position is indicated by values 1-7. Position 8 indicates the carriage is at the zero point. Position 0 indicates the carriage has not reached position 1 but is not at the zero point. The high nibble of XPOS does not contain valid data.

3.23 Sea Data Recorder (SD:)

Data gathered by the various sensors has been placed in specified locations on the global page as described above. The exact global page locations are defined in the equate table found in the program listing in Appendix C. Once every ten seconds this data is placed in order in a buffer (SS = x0, cycle 14H) by this module. The contents of the buffer are shown in Fig. 24b. During the following cycle the contents of the buffer are sent to the Sea Data recorder under DMA control. If the ?B command has been used, the contents of the buffer are also sent on the monitor SAIL loop in an easy to read ASCII format.

3.24 Return From Interrupt

The return from interrupt routines are at the end of the Long Branch Table. The contents of Register B are saved for use in the next interrupt. The status of SAIL Loop 1 is checked. If the loop is broken, the program

branches to a soft re-set routine (RESTRT) where the interrupt point (Register 1) is re-set, the stack re-set, Loop 2 broken, UARTS re-set and the system placed in the unaddressed state.

If Loop 1 status is not broken, the contents of the registers used outside of the interrupt are restored and the interrupt program counter (Register 1) is left pointing to the proper location for the next interrupt. Program control is transferred to the program counter (Register 3).

3.25 Sea Duct Sequencer

Like the monitor description, the sequencer description is broken into two major parts. First is a general introduction and description of the sequence commands. A more detailed description of the assembly coded modules comprising the individual sequencer commands follows the general description.

During normal Sea Duct deployment, the instrument is controlled using a high level instrument specific language. This language is comprised of easy to remember mnemonics placed in sequential order in a file by any text editor or word processor. Using the same assemblers as used for assembling the actual Sea Duct Program, a list of Pseudo Program Codes is generated. The main Sea Duct Program uses these simple codes as pointers to complex software modules which complete specific tasks.

Each mnemonic in the higher level Sea Duct sequencer language represents a specific Pseudo Program Code (PPC). The PPC is actually a pointer to an address in the program where the code for the specific task exists. Once per second, the program fetches the next PPC and executes the task. Occasionally the PPC will direct the program to re-enter itself several times during one

second. Some PPCs require longer than one second. Essentially, we have a list of simple commands that when translated into English could, for example, tell the system "wait until six o'clock, take a picture, wait one minute, start pump number one".

Like the monitor, general purpose portions of the sequencer have been used in many instruments. Other specific PPCs have been written for specific Sea Duct tasks. Table 1 presents the PPC's and the mnemonic for each sequencer function. Two distinct groups are presented. The first group consists of one byte (two character) functions and their respective arguments (when required); the PPCs in the second group are all prefixed with 'E0'. These 'E0' prefixes redirect the program to look in an extended list for the actual code indicated by the PPC.

3.26 Sequencer Command Description

The sequencer commands described in this section are listed as a group in Table 1. An example of a sequencer program written using the higher level mnemonics may be found in Appendix A. A rudimentary knowledge of a language such as BASIC or FORTH is assumed.

The monitor may be used to start, stop, and monitor progress of the sequencer. Monitor command descriptions for !S, ?S and !F should be understood.

The following descriptions show the conventions used:

_ represents a space.

aaaa represents a four character hexadecimal address.

When used with a mnemonic it represents a 1-6 character alpha-numeric label.

ASTK is the sequencer's general purpose arithmetic stack.

RSTK is the sequencer's return stack.

cccc represents a 4-character hexadecimal number used as stating value for the sequencer counters.

n or nn represent 1 or 2 character general purpose variables.

Idle loop When the sequencer is not in use it runs in an idle loop located at address 0F00 and 0F01. The loop works as follows:

MNEMONIC FORM

PPC FORM

IDLE: INITC
JUMP_IDLE

ADDRESS	PPC
0F00	4D
0F01	280F00

JUMP_aaaa (28_aaaa) This command is similar to BASIC's GOTO command. When the higher level mnemonic language (Sequencer language) is used the address must be a label in the program.

PUSH n (3n)

POP n (4n) Push or Pop n bytes to or from the ASTK. 30 = 1 byte, 31 = 2 bytes, 32 = 3 bytes, 33 = 4 bytes. Some instructions require bytes on the ASTK. The last byte placed on the stack is the first one to be removed. When mnemonics are used the actual value (1-4) should be used. For example, PUSH_3_01,02,03 will place 01,02,03 on the stack.

INITS (4C)

INITC (4D) These commands are used to clear the Sequencer ASTK, RSTK Fast Sequencer Modes and PPCNT. INITC additionally clears the three counters A, B, and C. INITC should be used at the start of each program. Occasional use during a program may prevent erratic sequencer operation by preventing an uncleared counter from redirecting the program at an unexpected time, etc.

GOSUB (60_aaaa)

RETURN (58) Subroutine commands. These commands work in a similar manner to corresponding basic commands. When the sequencer language is used the address must be a label in the program. The return address appears in the RSTK.

CLRABC (4E)

CLRCTn (n0) n = A,B,C

SETCTn cccc_aaaa (n1 cccc-aaaa) Counter Commands. Three general purpose software counters are available to the sequencer. The count (cccc) is a four digit hexadecimal number which is decremented once per second. When the count reaches 0000, program execution is immediately redirected to address aaaa. The counters can be cleared independently using CLRCTn or all at once using CLRABC. The command INITC also clears the

three counters. The counters continue to run unless cleared. In some cases the sequencer may appear to be stopped only to start up due to a forgotten counter. Be sure to clear a counter when it is no longer in use. The counters are cleared when the sequencer is in the idle loop.

WAITT (Time) (7n)

WAITF (Time) (8n) WAIT instructions. **WAITT** waits until the Real Time Clock (RTC) reaches the stack (ASTK) value. The stack value represents a number of Days for n = 0, Hours for n = 1, Minutes for n = 2, Seconds for n = 3. **WAITF** instructions wait for the interval of time shown on the stack. The stack value represents a number of Days for n = 1, Hours for n = 2, Minutes for n = 3. Seconds are not allowed for **WAITF** (See **WAITnn** instructions).

When mnemonics are used, the form is **WAITT DAYS** (HOURS, MIN, SEC). Values used by these instructions must be placed on the stack before the instruction is called. When used in combinations, LO order values should be placed on the stack first. For example, to wait for 2 days, 1 hour and 10 minutes, three values must be placed on the stack in the following order:

MNEMONICS	PPCs
PUSH 3 10,01,02	32 100102
WAITF DAYS	80
WAITF HOURS	81
WAITF MIN	82

NOOP (C4) No operation. This instruction does nothing except move to the next instruction. It is used in a tight loop to allow the program to be followed with the IF Monitor Command. For example:

```

LOOP: NOOP
      JUMP LOOP

```

can be followed with IF. The loop

```

LOOP: JUMP LOOP

```

will not appear to be tracked by IF because the PPC does not change.

L2OFF (D0)

L2ON (D1)

L2SEND (D2_aaaa) Loop 2 communications instructions. These instructions are used to control loop 2 and communicate with the flume pump control. **L2OFF** breaks loop 2 and shuts down the 20 mA. loop supply. **L2ON** turns on loop 2 and closes the

loop. **L2SEND** turns on loop 2, closes the loops and sends data on the loop. Data is sent from a list located at aaaa. For example, to address the pump controller, the address **#PC_** must be sent.

```
L2SEND_LIST
.
.
LIST: DB"#PC_"
DB_90
DB_FF
```

Note that the list is not in the PPC program area but placed, say, at the end of the program. The 90 instruction in the list tells the loop controller to wait for an ETX to be sent by the pump controller. FF must be placed at the end of a list to signify the last character to be sent. Users should adhere to the SAIL Protocol (Ref. 9).

BAT n (E0 1n) N = 1,2,3 Pulse System Battery Relay n. The relay is pulsed to turn the battery on, again to turn it off. Be careful to keep count! It could be easy to lose track and turn the system off when it should be turned on!

PING (E0 24)

SEND n (No PPC) n = 0-F Acoustic transponder control. **PING** sends the value (00-0F) found on the ASTK. **SEND n** automatically places the proper value on the stock and then calls the **PING** instruction. The character is sent by the transceiver once per second for thirty seconds. Table 2 presents the pinger codes currently used by the system.

ADOFF (E030)	A/D On
ADON (E031)	A/D Off
TROFF (E040)	Transmissometer On
TRON (E041)	Transmissometer Off
SDOFF (E050)	Sea Data Recorder On
SDON (E051)	Sea Data Recorder Off

These instructions are self explanatory. The A/D should be turned on before turning on the transmissometer.

CHKTLT (E0 70) Check tilt. This command checks the roll and pitch of the system. If the roll or pitch is within +/- 3 degrees of level the acoustic signal "C" (Tilt OK) is sent. Signal "D" (Tilt Bad) is sent if the instrument is more than 3 degrees away from level.

HYDRA (E0 A8) This command pulses the latching relay controlling the hydraulic pump motor. It must be used in conjunction with instructions that use the hydraulic system. Examples shown in Appendix A illustrate **HYDRA**'s use.

ROTCW (E0 80)

ROTCCW (E0 81) These instructions rotate the test section clockwise and counter-clockwise. The **HYDRA** instruction must be used in conjunction to turn on the hydraulic system before using **ROTCW** or **ROTCCW** and again to turn off the system. **ROTCW** and **ROTCCW** pulse latching relays. For example, to start and then stop clockwise rotation, the following commands would be used:

```
HYDRA ; Start the Hydraulic System
ROTCW ; Start CW Rotation
ROTCW ; Stop CW Rotation
HYDRA ; Stop the Hydraulic System
```

These instructions are not normally used because they do not sense rotation position.

ROTRIN (No PPC)

ROTHDG (No PPC) These are the preferred flume rotation instructions. **ROTHDG** rotates the flume to the predetermined heading specified using the !H monitor command. **ROTRIN** returns the flume to the transport position. The **HYDRA** instruction must also be used with these commands. If the rotation is not completed correctly, the acoustic transponder will send signal 'B'. It is important to note that the flume must not be rotated when the flume is in the "inserted" position.

ZEROX (E0 9A)

INCX (E0 9B)

ZEROY (E0 9C)

INCY (E0 9D)

ZEROZ (E0 9E)

INCZ (E0 9F)

XYZ0 (No PPC) LDV and Camera Carriage Position. These instructions are self explanatory. **HYDRA** must be used with all of these with the exception of **XYZ0**, which includes hydraulic control. If an error is detected the transponder will send code 'A' for 30 seconds. Errors are caused when the carriage does not reach the proper position within 60 seconds (120 seconds for X). **XYZ0** does not have a single PPC - it is a macro instruction which actually calls **HYDRA**, **ZEROZ**, **ZEROY**, **ZEROZ**, **HYDRA**.

FMPRLY (E0 AE)

FMPOFF (No PPC)

FMP1_nn (No PPC)

FMP2_nn (No PPC) These are macro instructions which control the flume pump motors. The argument nn is a two-digit hexadecimal number (00-FF) which allows control of each pump in 246 steps. Values less than 10 should not be used because the motors stall at such low speeds. Value 00 is used to turn off the pumps.

PMPRLY controls a latching relay which controls power to the pump system. It must be used in a similar manner to HYDRA; i.e., it must be called at the start and end of pump operations. If it is used during pump operations, it will shut down the pump system.

PMP1 and PMP2 power loop 2, address the selected pump, set it to the proper speed, and then remove power from loop 2. The pump speed locations on the global page are updated by the SPMP routines which are called by these PMP macros. PMPOFF turn both pumps off. Examples of the use of these instructions can be found in Appendix A.

CAMERA (E0 C0) Takes a picture with the Photosea Camera System.

LDVRS (E0 D0) Momentarily closes the LDV computer reset switch. It is used at the present time to start the LDV before the actual experiment portion of a deployment. Note that the LDV is not connected to Loop 2 in the present configuration.

SEDINS n (E0 A1, E0 A5)

SEDRET n (E0 A2, E0 A6)

SEDUNL n (E0 A3, E0 A7) Sediment core instructions. Core samplers 1 and 2 can be inserted and retracted. **SEDUNL n** unlatches the doors on the core samplers. These instructions drive latching relays which open or close hydraulic valves. For example, **SEDINS 2** will start inserting core sampler #2. Repeating the command will stop the insertion. **HYDRA** must be used in conjunction with these commands.

FLUMIN (E0 AC)

FLUMOUT (E0 AD) These instructions are used to insert and retract the test section. These instructions drive latching relays which open or close hydraulic valves. For example, **FLUMIN** will start inserting the flume. Repeating the command will stop the insertion. **HYDRA** must be used in conjunction with these commands.

BRBOT_aaaa (E0 F0 aaaa)

BRINS_aaaa (E0 F1 aaaa)

BRRET_aaaa (E0 F2 aaaa) Sense switch instructions. These instructions are conditional branch instructions. They may be used to create complex control sequences. Examples may be found in Appendix A.

BRSIGA_aaaa (E0 F8 aaaa)

BRSIGB_aaaa (E0 F9 aaaa)

BRSIGC_aaaa (E0 FA aaaa) These instructions are conditional branch instructions that cause the program to branch when the acoustic transponder receives a command signal from the surface. Examples of use can be found in Appendix A.

WAIT10	WAIT 29	WAIT 1M
WAIT20	WAIT 59	WAIT 2M
WAIT30	WAIT 60	WAIT 5M (No PPCs for these instructions.)

These instructions allow precise timing functions not obtainable with the WAITF instructions. They actually call subroutines that utilize sequencer counter C. They are found on the "include file" ISDSUB.MAC.

TABLE 1
SEA DUCT SEQUENCER
BASIC FUNCTIONS (NO PREFIX)

CODE	PNEMONIC	FUNCTION
28 aaaa	JUMP aaaa	Jump PPC to Address aaaa
3n	PUSH n	Push n bytes to ASTK 30 = 1 byte 31 = 2 bytes 32 = 3 bytes 33 = 4 bytes
4n	POP n	Remove n bytes from ASTK 30 = 1 byte 31 = 2 bytes 32 = 3 bytes 33 = 4 bytes
4C	INITS	Initialize SEQ. Stack Pointer Clears ASTK, RSTK, Fast Sequencer Modes, and PPOCNT
4D	INITC	Initialize SEQ. Stack Pointer and Counters Clears ASTK, RSTK, Fast Sequencer Modes, PPOCNT and Counters A, B, C
4E	CLRABC	Clear Counters A, B, C
5s	RETURN	Return from Subroutine
60 aaaa	GOSUB aaaa	Go to Subroutine at PPC = aaaa
7n	WAITT	Waits till RTC = Stack value of: 70 = Days 71 = Hours Stack bytes are 72 = Min considered as 73 = Sec 2 BCD digits. Fill stack with 10 first if used in groups.
8n	WAITF	Waits for Stack Interval 80 = Days Stack contains 81 = Hours the time in- 82 = Min terval (Hex) 83 = Not of days, hours Allowed or min.
A0	CLRCTA	Clears Counter A
A1 cccc aaaa	SECTCA cccc,aaaa	Set Counter cccc = count in seconds (Hex) aaaa = PPC vector @ count-0000
B0	CLRCTB	Clears Counter B
B1	SECTCB cccc,aaaa	See Counter A Instructions
C0	CLRCTC	Clears Counter C
C1	SECTCC cccc,aaaa	See Counter A Instructions
C4	NOOP	No Operation - Increments PPC
D0 (aaaa)	L2OFF L2ON L2SEND	D0 = Loop 2 PWR OFF D1 = Loop 2 PWR ON D2 aaaa = Loop 2 PWR ON and send data list at M(aaaa) List at M(aaaa) must be: ASCII = Sends the character 90 = Wait for ETX FF = End of List Note: 60 Sec. time out on L2SEND. Sets Loop 2 error bit and goes to next PPC.
E0	Extended Sequencer	Enables Extended Sequencer functions with E0 prefix.

TABLE 1 (contd)
SEA DUCT SEQUENCER
BASIC FUNCTIONS (NO PREFIX)

CODE	MEMONIC	FUNCTION
E0 1n	BAT n	Pulse Main Battery Relay E0 10 = Not Allowed (does Nothing) E0 11 = Relay 1 E0 12 = Relay 2 E0 13 = Relay 3
E0 24	PING	Key Telemetry Pinger (1 Hz. Rept. Rate for 30 Sec.) Telemetry code MUST be on ASTK Telemetry code = 0n, where n = 0-F See Pinger Code List
	Send n	Sends Pinger Code n (n = 0-F)
E0 30	ADOFF	A/D Off
E0 31	ADON	A/D On
E0 40	TROFF	Transmissometer Off
E0 41	TRON	Transmissometer On
E0 50	SDOFF	Sea Data Recorder Off
E0 51	SDON	Sea Data Recorder On
E0 60	SRMP0	Set Pump 1,2 on GPAGE = 00 (No immediate byte)
E0 61 nn	SRMP1 nn	Set Pump 1 on GPAGE = nn (nn = Hex)
E0 62 nn	SRMP2 nn	Set Pump 2 on GPAGE = nn (nn = Hex) These instructions are called by RMPL, RMP2, and RM
E0 70	CHKTLT	Check Roll and Pitch Send Acoustic Signal: "C" = Tilt OK = 3 Degrees "D" = Tilt Bad
E0 8n		Flume Rotation Control: ROTOW E0 80 = Rotate CW ROTOW E0 81 = Rotate CCW ROTOW E0 82 = Rotate to Transport Position ROTOW E0 83 = Rotate to Experiment Position ROTOW Rotation errors send acoustic ROTOW code "B".
E0 9n		XYZ Position Control: E0 90 = Pulse X+ Relay No Macro Assy E0 91 = Pulse X- Relay codes for E0 92 = Pulse Y+ Relay these six E0 93 = Pulse Y- Relay instructions E0 94 = Pulse Z+ Relay E0 95 = Pulse Z- Relay ZEROW E0 9A = X Pos Zero INCX E0 9B = X Pos Increment ZEROW E0 9C = Y Pos Zero INCY E0 9D = Y Pos Increment ZEROW E0 9E = Z Pos Zero INCZ E0 9F = Z Pos Increment E0 96-99 are not used and do nothing. Position errors send acoustic code "A". Hydraulic Pump power is not controlled with these instructions. Time out = 120 Sec. for X0 60 Sec. all others
	XYZ0	Return Carriage to X0, Y0n, Z0 Includes Hydraulic Pump Control
E0 An		Sediment and Water Samplers; Pumps and View Port Cleaner E0 A0 = Spare #4 E0 A4 = Spare #5 E0 A1 = Sed.1 Insert E0 A5 = Sed.2 Insert E0 A2 = Sed.1 Retract E0 A6 = Sed.3 Retract E0 A3 = Sed.1 Unlatch E0 A7 = Sed.2 Unlatch and H20 1 and H20 2 HYDRA E0 A8 = Hydraulic Pump E0 A9 = Spare #1 E0 AA = Spare (Suction Pump) E0 AB = Spare (Clean View Port) FLUMIN E0 AC = Insert Flume Does not include FLUMOUT E0 AD = Retract Flume hydraulic control.

TABLE 1 (contd)

SEA DUCT SEQUENCER
BASIC FUNCTIONS (NO PREFIX)

CODE	MNEMONIC	FUNCTION
	PMPLY	E0 AE = Pulses Recirc. Pump Power Relay E0 AF = Old Recirc. Pump #2 (does nothing)
	PMPOFF	Sets Pump 1, 2 = 00
	PMPL nn	Sets Pump 1 to nn (Hex)
	PMP2 nn	Sets Pump 2 to nn (Hex) Does not include PMPLY Command Also calls SPMP instructions to set pump speeds on the global page.
E0 C0	CAMERA	Camera - Take a picture
E0 D0	LDVRST	Reset LDV
E0 Fn aaaa		Branch on Switch n to aaaa where aaaa = Branch address
	BRBOT	E0 F0 = Bottom contact switch
	BRINS	E0 F1 = Flume insertion switches (4) (S1 and S2 and S3 and S4)
	BRRET	E0 F2 = Flume Retracted Switch
		E0 F3-F7 = INVALID CODES
	BRSIGA	E0 F8 = XPNDR Sig. A
	BRSIGB	E0 F9 = XPNDR Sig. B
	BRSIGC	E0 FA = XPNDR Sig. C
		E0 FB-FF = INVALID CODES

INCLUDE FILE - ISDSUB.MAC:

WAIT10	Wait for 10 Sec.
WAIT20	Wait for 20 Sec.
WAIT29	Wait for 29 Sec.
WAIT30	Wait for 30 Sec.
WAIT59	Wait for 59 Sec.
WAIT60	Wait for 60 Sec.
WAIT1M	Wait for 1 Min.
WAIT2M	Wait for 2 Min.
WAIT5M	Wait for 5 Min.
WAIT7M	Wait for 7 Min.

TABLE 2
SEA DUCT PINGER CODES

0 Program Start, End Transmiss. Test,	8 Off the bottom
1 Start Transmiss. Test, Beginning Rotation On Bottom,	9 OK to lift and move to a new position
2 End of Rotation	A XYZ Position Error
3 Start of Insertion	B Rotation Error
4 Insertion "OK"	C Tilt "OK"
5 Insertion "Bad"	D Tilt "Bad"
6 Start Core	E (Not used at the present time)
7 Start of Velocity Measurement Series	F Ready to drop weight

3.27 PPC Command Sequences for SAIL Control

In order to implement easy manual control of the Sea Duct without the manual control box, a special sequencer control file has been created. This file usually resides in battery backed RAM in locations 3800H - 3FFFH. The monitor command !S can be used to run the sequencer to execute these simple commands. Table 3 shows these commands and the PPCs that they call. For example, to retract the flume the sequencer is run at address 3D20H. These instructions return the sequencer to the idle loop (0F00) when they have completed their task. Table 4 lists the actual contents of the file SDCMD. RCA used to load these commands into the Sea Duct. The same file can be stored on a Radio Shack TRS-80 Model 100 as SDCMD.DO. When the file is correctly loaded, the CRC from 3800 over 0800 locations will be D4D1. Appendix F gives details for use of the Radio Shack Model 100 with the Sea Duct SAIL system.

TABLE 3
SEA DUCT SEQUENCER COMMANDS
27 MARCH 1986

COMMAND	ADDRESS	PPCs
	IM ;	
Bat 1	3800	4D E011 280F00;
Bat 2	3810	4D E012 280F00;
Bat 3	3820	4D E013 280F00;
Hydraulic pump	3830	4D E048 280F00;
Check Tilt	3870	4D E030 C4C4 E070 280F00; C=OK, D=BAD
Rot. CW	3880	4D E080 280F00;
Rot. CCW	3890	4D E081 280F00;
(Requires Separate Hydraulic Control)		
Camera	38C0	4D E0C0 280F00;
Zero X	3900	4D E0A8 E09A E0A8 280F00;
Inc. X	3910	4D E0A8 E09B E0A8 280F00;
Zero Y	3920	4D E0A8 E09C E0A8 280F00;
Inc. Y	3930	4D E0A8 E09D E0A8 280F00;
Zero Z	3940	4D E0A8 E09E E0A8 280F00;
Inc. Z	3950	4D E0A8 E09F E0A8 280F00;
(Includes Hydraulic Control)		
ROTRTN	3A00	4D E0A8 E082 E0A8 280F00;
ROTHDG	3A10	4D E0A8 E083 E0A8 280F00;
(Includes Hydraulic Control)		
Flume Down	3B00	4D E0AC 280F00;
Flume Up	3B10	4D E0AD 280F00;
(Requires Separate Hydraulic Control)		
Flume Pump		
Pwr Relay	3B20	4D E0AE 280F00;
Reset LDV	3BD0	4D E0D0 280F00;
Sed. 1 Insert	3C00	4D E0A8 E0A1 C4C4 C4C4 C4C4 E0A1 E0A8 280F00;
Sed. 1 Unlatch	3C20	4D E0A8 C4C4 E0A3 C4C4 E0A4 E0A8 280F00;
Sed. 1 Reset	3C40	4D E0A8 E0A2 C4C4 C4C4 C4C4 E0A2 E0A8 280F00;
(Includes Hydraulic Control)		
Sed. 2 Insert	3C60	4D E0A8 E045 C4C4 C4C4 C4C4 E0A5 E0A8 280F00;
Sed. 2 Unlatch	3C80	4D E0A8 C4C4 E0A7 C4C4 E0A7 E0A8 280F00;
Sed. 2 Reset	3CA0	4D E0A8 E0A6 C4C4 C4C4 C4C4 E0A6 E0A8 280F00;
(Includes Hydraulic Control)		
Insert Flume	3D00	4D E0A8 E0AC E0F13D0C 283D05 E0AC E0A8 280F00;
(Includes Hydraulic Control)		
Retract Flume	3D20	4D E0A8 E0AD E0F23D2C 283D25 E0AD E0A8 280F00;
(Includes Hydraulic Control)		

TABLE 4

SEA DUCT SEQUENCER COMMAND FILE

```

SDCMD.DO (M-100)
SDCMD.RCA (CPM)
!M3800 4D E011 280F00;
3810 4D E012 280F00;
3820 4D E013 280F00;
3830 4D E0A8 280F00;
3870 4D E030 C4C4 E070 280F00;
3880 4D E080 280F00;
3890 4D E081 280F00;
38C0 4D E0C0 280F00;
3900 4D E0A8 E09A E0A8 280F00;
3810 4D E0A8 E09B E0A8 280F00;
3920 4D E0A8 E09C E0A8 280F00;
3930 4D E0A8 E09D E0A8 280F00;
3940 4D E0A8 E09E E0A8 280F00;
3950 4D E0A8 E09F E0A8 280F00;
3A00 4D E0A8 E082 E0A8 280F00;
3A10 4D E0A8 E083 E0A8 280F00;
3B00 4D E0AC 280F00;
3B10 4D E0AD 280F00;
3B20 4D E0AE 280F00;
3BD0 4D E0D0 280F00;
3C00 4D E0A8 E0A1 C4C4 C4C4 E0A1 E0A8 280F00;
3C20 4D E0A8 C4C4 E0A3 C4C4 E0A3 E0A8 280F00;
3C40 4D E0A8 E0A2 C4C4 C4C4 E0A2 E0A8 280F00;
3C60 4D E0A8 E0A5 C4C4 C4C4 E0A5 E0A8 280F00;
3C80 4D E0A8 C4C4 E0A7 C4C4 E0A7 E0A8 280F00;
3CA0 4D E0A8 E0A6 C4C4 C4C4 E0A6 E0A8 280F00;
3D00 4D E0A8 E0AC E0F1 3D0C 28 3D05 E0AC E0A8 28 0F00;
3D20 4D E048 E0Ad E0F2 3D2C 28 3D25 E0AD E0A8 28 0F00

```

CRC = D4D1/800
@ 3800

To load from M-100 to Sea Duct use Text Mode - Full Duplex is OK
Use SAVE COM:37E1D. The M-100 telecom mode can also be used.

To load from the CPM/computer system to Sea Duct use MCALL
Set MCALL for Echoplex, 2400 Band, X-On/X-Off, 7 data Even parity,
1 stop bit.
See Appendix F for more details.

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